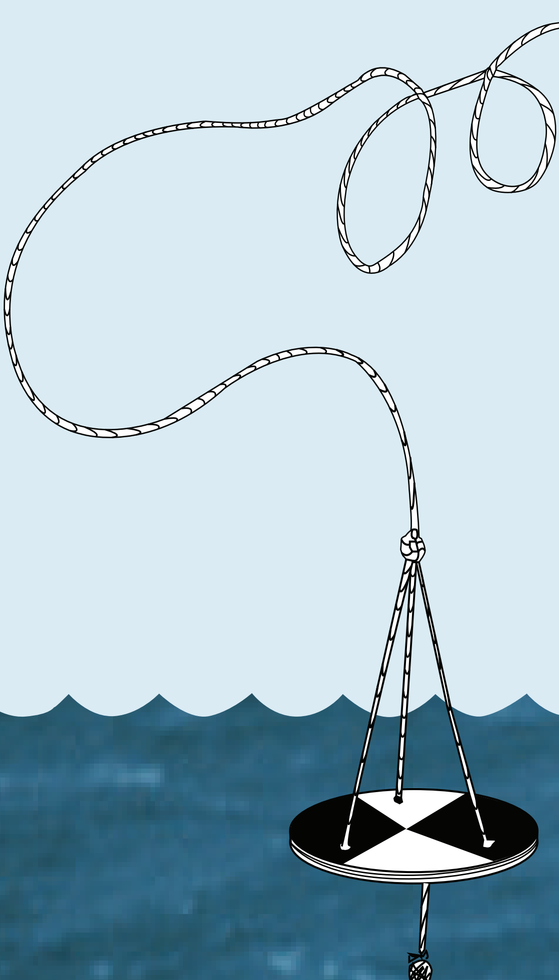
Oceanography:

An Observer's Guide



For:
sailors,
fishermen, yachtsmen,
merchant seamen,
Navy and Coast Guard
personnel, midshipmen
and cadets, Sea
Semester students...
...and everyone else
going to sea.

Nelson Marshall

Oceanography: An Observer's Guide

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Beginning as a small college laboratory and a state research and education agency, UMCES has developed into a multi-campus institution of Maryland's university system. UMCES continues its rich tradition of discovery, integration, application and teaching at its three laboratories: Chesapeake Biological Laboratory (1925), Appalachian Laboratory (1962), and Horn Point Laboratory (1973), Maryland Sea Grant in College Park, MD and the Annapolis Synthesis Center in downtown Annapolis. The Integration and Application Network was established in 2002 to allow UMCES to apply the scientific knowledge of its faculty and staff to the environmental challenges we face today.

Oceanography: An Observer's Guide

by Nelson Marshall

Professor Emeritus of Oceanography and Marine Affairs, University of Rhode Island

Coordination, design, and layout by Emily Nauman

Preface

During my career as an oceanographer I have sailed on ships equipped with very sophisticated instruments and yet, while cruising on my own thirty-foot sailboat, it occurred to me that many meaningful observations can be made with the equipment on board even the most modest vessels that go to sea.

For example, a thermometer, a wind gauge, a depth finder, a wrist watch, ordinary buckets, some note paper, and much more that is readily available, can be useful to an observer interested in learning more about the surroundings. Actually, one's eyes can serve as the best equipment of all, once one knows what to look for.

Accordingly, I have written this guide for sailors, yachtsmen, sport and commercial fishermen, merchant seamen, Navy and Coast Guard personnel, midshipmen and cadets, sea semester students, in fact for anyone traveling on the high seas.

The scope of this book is largely limited to conditions on the high seas because covering offshore-inshore interactions would require an additional and very lengthy book. However, I do bridge gaps to some degree, particularly in a brief chapter at the end titled, *What about Estuaries?*

Being largely restricted to features that can be discussed on the basis of observations on the surface, it is obvious that this guide does not cover some important aspects of oceanography. Even so, I am confident that anyone traveling on the high seas can learn a great deal by observing and with the simplest of equipment.

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Acknowledgements

While writing this guide I have been regularly visiting the College of Oceanographic and Atmospheric Sciences at Oregon State University where Bill Pearcy, Charlie Miller, Doug Reese, Jane Huyer, Bob Smith, Kelly Faulkner, Gary Egbert, Charlie Goldfinger, Murray Levine, Jonathon Nash, Mike Kozro, Ernie Pertersen, George Taylor, Bruce Mate, Doug Caldwell, Clayton Paulson and many others have been especially helpful in responding to my many inquiries. In addition, I wish to extend a special thanks to Linda Lafleur, receptionist at the college, who constantly looked after my various needs in relation to offerings at Oregon State University.

Several of my former students, especially Thierry Jacques, Hank Parker, Ray Gerber, Barbara Welsh and her husband, Bob, helped in supplying information and reviewing drafts of my writing. In addition, my former Dean, John Knauss, reviewed the discussion of Law of the Sea provisions. Karen Wishner, another colleague at the University of Rhode Island, provided updated information on the subsurface volcano in the Caribbean.

Many members of the University of Maryland Center for Environmental Science (UMCES) played a range of contributing roles including providing basic information and helping to organize and review the text. Leading this group was Bill Dennison. Others included Bill Boicourt, Larry Sanford, Judy O'Neil, Roger Newell, Tom Fisher, Ben Longstaff, Emily Nauman, Emily Benson, and Joanna Woerner.

Bob Shoop and Paul Hargraves of the University of Rhode Island, Paul Joyce of the Sea Education Association, Bill Dillon of the U.S. Geological Survey, Hugh Ducklow of the Ecosystems Center of the Marine Biological Laboratory, Nat Mantua and Knut Aaguard of the University of Washington, Amy Schoener formerly with the University of Washington, and Jack Bash, formerly with the University Oceanographic Laboratory Ships organization are among the many others who have provided important information.

You may note that many of the fine illustrations that are original with this publication or are taken from one of my earlier writings were drawn by my colleague, Debbie Kennedy.

Assistance in editing was provided by several of the above, also by my son-in-law, David Griffiths, who is on the Faculty of Reed College.

Foreword

Oceanography: An Observer's Guide uniquely captures the perspectives of both an oceanographer and a mariner—Nelson Marshall has excelled at both over a long and varied career and life. In this book, the physics, chemistry, biology, and geology of the oceans are presented in a way that virtually everyone can understand. The title, *Oceanography: An Observer's Guide,* better captures the spirit of what Nelson Marshall does with this book—he conveys the importance of using the power of observation with little or no accompanying instrumentation to understand nature. This is a powerful lesson, and one of the iconic figures in marine science, Louis Agassiz, who ran a summer program on an island off Cape Cod, Massachusetts in the 1870s, captured this lesson in his famous sign that read "Study nature, not books." Ironically, this sign resides in one of the world's greatest marine science libraries at the Marine Biological Laboratory in Woods Hole, Mass. Nelson Marshall's book is teaching us how to study nature by providing us with enough of the background and conceptual framework to make observations ourselves. So while this lesson of how to "Study nature, not books" is provided in a book, it is a book intended to be taken to sea so that observations can be enhanced and the mariner can study nature firsthand.

In our modern age, increasing numbers of sensors measure the Earth in various ways. With the increasing information instantly available via the internet, simply using our eyes to observe the Earth, particularly the 70% of the Earth covered by water, has become a novel approach. We should not ignore the wonders that technology can bring to our fingertips; however the act of looking, that is keenly observing, is often indeed 'overlooked'. Nelson Marshall has kindly provided us with some guidelines on observing.

Scientific specialization has made the task of crossing the various disciplines that Prof. Marshall has done so seamlessly, an increasing rarity. Perhaps a result of the broad-based training that Nelson Marshall received in the early days of oceanography, chronicled in his book, *In the Wake of a Yankee Oceanographer*, or a result of his varied and diverse career, Prof. Marshall has the unique breadth and depth of understanding to undertake such an ambitious scope presented in this book.

Another remarkable facet of the book is the combination of his historical perspective with modern concepts and understanding. Prof. Marshall has indeed defined what it is to have had a lifelong learning experience. After his first retirement from an active and varied career culminating at the University of Rhode Island's School of Oceanography, he came to the Chesapeake Bay, where he and his wife, Grace, could sail regularly. Nelson struck up an active participation at the Horn Point Laboratory, University of Maryland Center for Environmental Science, where he challenged graduate students and professors with insightful questions and began writing books. He then retired (again) to Oregon, where he continued to make weekly sojourns to Oregon State University, even sitting in on seminars—the only octogenarian graduate student. This book benefits from Nelson's wealth of firsthand experience in the corridors of research institutions and sailing on tall and small ships on the world's oceans. This book was Nelson's final project, as he passed away on the day that the manuscript went to the printer.

One way to read this book is to imagine yourself standing along the rail of a ship alongside your favorite uncle as he patiently explains what is unfolding in front of your eyes. As you absorb this information, your eyes are widening and your brain is filling with thoughts that allow you achieve a deeper understanding of the world—a deep learning experience that forever enriches your life. If reading this delightful book helps you to better see, really see, the world around you, then this kind and gentle uncle, Professor Marshall, has achieved what he intended.

William C. Dennison
University of Maryland Center for Environmental Science

Dedicated
to
Grace

My Wife and Sailing Companion

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Chapter I.
The Challenge of Observing While at Sea

It's a challenge and it's very rewarding. During your time at sea you can learn a great deal about the oceanography of your surroundings by simply observing and interpreting what you are seeing. This guide should help you to meet this challenge.

I can't think of a better example of the results of keen observing than the contribution of Charles Darwin in explaining the process of atoll formation.

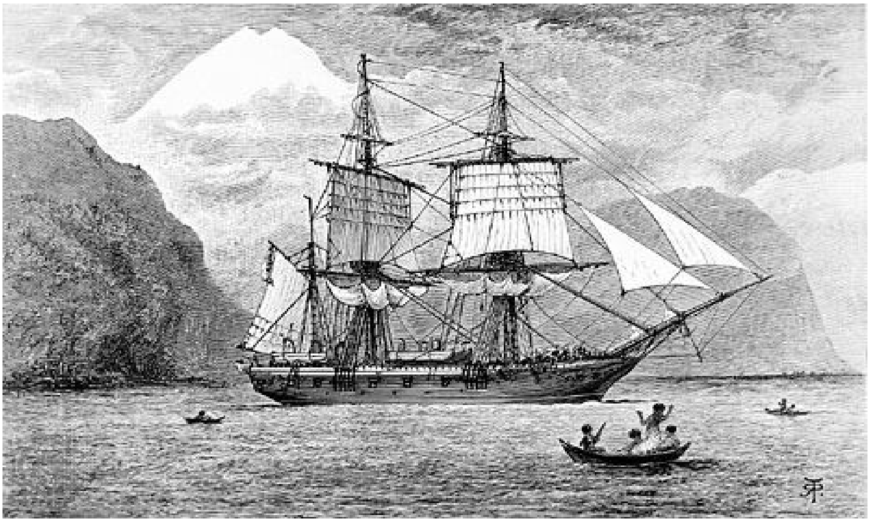


Fig. 1. HMS Beagle in the Straits of Magellan. From Order of the Proceedings at the Darwin Celebration, Cambridge, 1909.

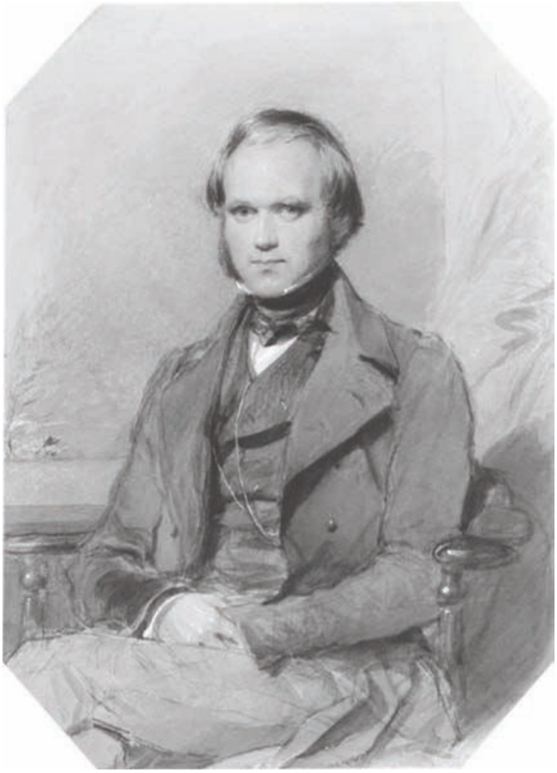


Fig. 2. Charles Darwin as a young man, shortly after he served as naturalist on board the Beagle. *From Charles Darwin's* Diary of the Voyage of the *H.M.S. Beagle. Cambridge University Press, 1933.*

As the HMS *Beagle* (Fig. 1) was sailing through the South Pacific and Indian Oceans, many high volcanic islands and coral atolls came into view. Darwin, (Fig. 2) who was on board in the role of expedition naturalist, could see that the coral reefs around the volcanic islands ranged from those that fringed the shoreline to barrier reefs offshore. From this he reasoned that atolls formed when the barrier reefs continued to grow while the volcanic terrain was subsiding to depths below the surface (Fig. 3, 4). He commented as follows: "We see in each barrier-reef a proof that the land has there subsided, and in each atoll a monument over an island now lost."

Darwin's interpretation was all the more remarkable since, at the time, the concept of gradual geological change such as must be involved in the sinking of volcanic islands, was new to science and was not as yet widely accepted. And his theory was questioned for other reasons, particularly by those who thought that rising sea level provided the basic explanation of atoll formation. However, in 1952 in a drilling operation on the rim of Eniwetak Atoll, the original volcanic foundation, now deeply submerged, was not reached until 1200 m (3936 ft). The accumulation above was carbonate rock from the build-up of reef structure.

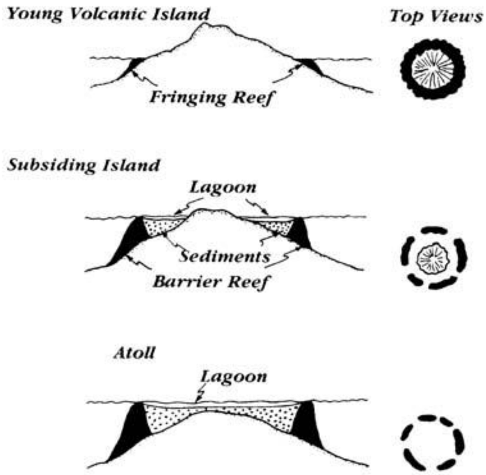


Fig. 3. Successive stages in the development of an atoll.

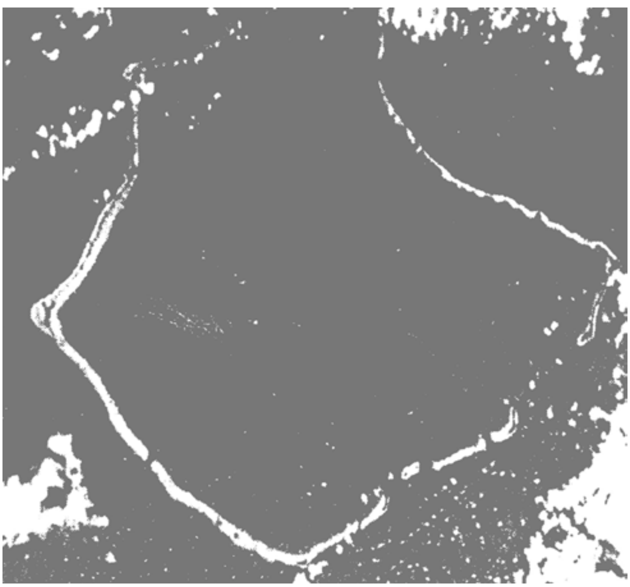


Fig. 4. Rongelap Atoll in the Marshall Islands. The lagoon is enclosed by the linear outline of the atoll reef. Source: NASA.

This is the story of a great naturalist using surface observations to piece together a very significant oceanographic process. Darwin didn't have sophisticated equipment. His knowledge of anything below the surface was limited to some sampling with a lead line. Surface observations and a driving curiosity were his basic tools.

In keeping with this example, I have developed this study guide. Often I make specific suggestions as to processes you should look for. Otherwise I discuss the oceanography involved in a style intended to encourage you to use your own initiative as you observe and interpret your surroundings. While the title, *Orientation,* is used in the chapter that follows, orientation is a theme that continues throughout the entire text, chapter by chapter.

Addendum:

Though I emphasize what can be accomplished without special instrumentation, it is useful to note that, on any vessel large or small traveling the high seas, much of the ordinary equipment readily available may enhance one's observations. It was while cruising on my own thirty foot auxiliary sloop that I realized this and started thinking about how much observers could achieve. A listing of such ordinary equipment that enhances one's observations follows:

- Compass
- Navigation charts
- Barometer
- Depth sounder
- Lead line
- Wind gauge
- Thermometer—one that retains a sample of water is to be preferred
- GPS (Ground Positioning System)
- Sextant—not essential but useful when observing celestial bodies
- Watch with quartz crystal and indicating seconds
- Field glasses
- Searchlight
- Flashlight
- Ruler, or yard or meter stick
- Bucket
- Dip net

You might add a Secchi disc, easily made by following instructions in Chapter X. It also helps to add field guides, star finders, and other readings noted at the end of the following chapters. Not to be overlooked is the fact that one's eyes, coupled with normal and natural curiosity, are the most useful equipment of all.

Chapter II.
From the Coast to the Depths of the High Seas: *An Orientation*

The oceans cover 70 percent of the Earth's surface. Moreover, considering the volume and extensive bottom surfaces, the oceans must provide at least 95% of the area suitable for life on the surface of the Planet. A brief orientation to this vast expanse is obviously needed. So let's take a journey from the coast well out onto the high seas. This will start with the headlands and beaches and continue to waters far out over the deep ocean basins.

On the headlands, where the rocks are exposed to the rise and fall of the tide, the vertical zonation of the flora and fauna is quite impressive (Fig. 1). At the highest levels, wetted only by spray and occasional waves, the rock surface may appear black due to tightly adhering blue-green algae and lichens. You may see snails scraping and grazing on this and on the vegetation lower down. Continuing downward in the intertidal there is often an abundance of barnacles. And you may find copious algal growth in the frequently wetted areas. On the completely submerged rock surfaces there is often a luxuriant growth of marine algae, including rockweeds. Although such vertical zonation is most pronounced where the range of the tide is substantial, you may see the same patterns, in a somewhat compressed form, where the tidal range is only a foot or so. (For anyone seeking more detail as to the nature of such intertidal zones, references are listed at the end of this chapter.)

The beaches range from above the highest tides down to the shoreline. (See Chapter XIX for information on beaches.) Just offshore of the beaches and headlands, there is typically an expanse of breakers. The

Rocky shore: Who lives where?

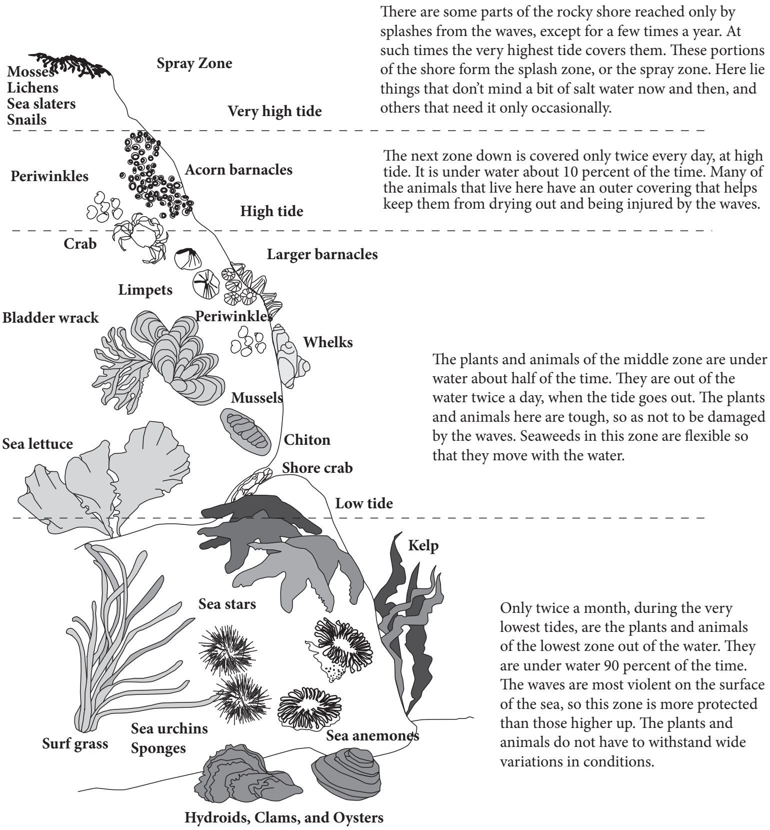


Fig. 1. Intertidal zonation on a rocky headland. Source: The Beach Book*, Pacific Educational Press, Vancouver, British Columbia.*

bottom under and just beyond this breaker zone may consist of a series of submerged sand bars paralleling the shoreline. In the tropics there may be a fringing reef of corals along the shore, then a lagoon, and a barrier reef not far offshore. (Refer to Chapter XVI for a discussion of coral reef environments.)

Beyond the bars and the reefs you can follow the trends with your depth finder. You are over the continental shelf which is essentially the submerged shoulder of the continental land mass. Along the East Coasts of the Americas and extensively around the world, the continental shelf may be 320 km (200 miles) wide. Areas where it is even wider include the shelf off the Southeast Coast of South America extending all the way to the Falkland Islands[1]; also the shelf off Newfoundland with the Grand Banks far to the east. However, off some coastlines including the West Coasts of the Americas, the shelf is quite narrow (Fig. 2).

Though, in general, the depths increase as you get farther from the shore, various offshore banks, canyons, and other features add variety to the shelf topography. Some of the banks are the outwash areas of former glaciers. Georges Bank off New England is a good example of such an outwash area. And some of the canyons cutting into the outer shelf areas are drowned river valleys, relics of glacial times when sea level was much lower than it is today. For example, the Hudson Canyon, far off the mouth of the Hudson River, was eroded into the edge of the shelf when the sea had receded (Fig. 3). Most everywhere such features are well defined on the navigation charts and to some extent you can follow the varied depths with an ordinary fathometer.

As you cross the shelf you may see considerable fishing activity, both commercial and recreational, since these relatively shallow waters, are generally quite productive, being enriched as nutrients are mixed into the water column. (Refer to Chapter IX dealing with plankton productivity and to Chapter XIV discussing the fisheries for more information.) Also,

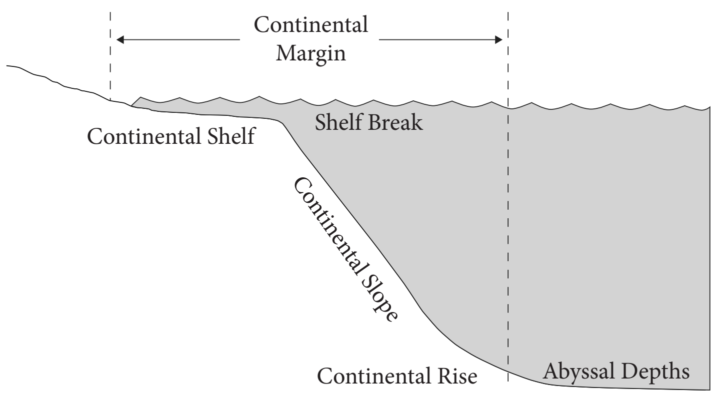


Fig. 2. Profile of depths from the continent to the abyss. Source: Sea and Air: The Naval Environment b*y Williams, Jerome, John J. Higginson, and John D. Rohrbough, 1986. United States Naval Institute, Annapolis, Maryland.*

1 In laying claim to the Falklands, Argentina stressed the fact that the shelf off its coast encompassed these islands. However, Great Britain made claims based on occupation. A war followed and Great Britain prevailed.

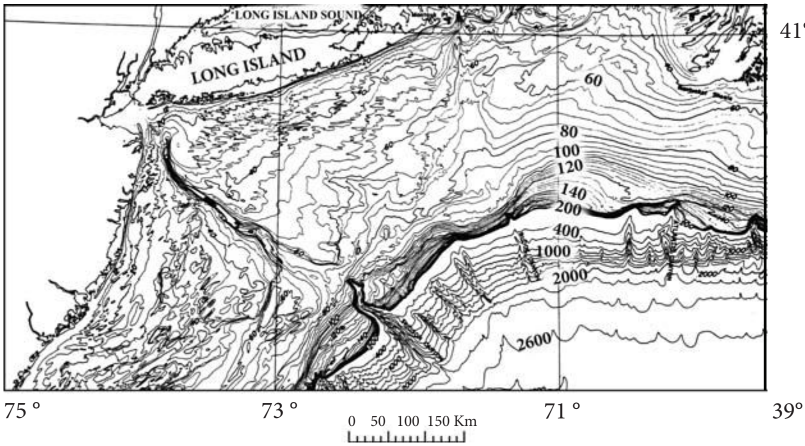


Fig. 3. Contours of the continental shelf off the Mid-Atlantic (New York) Bight. Note the large Hudson Canyon cutting into the shelf along the bottom left of the illustration. Source: NOAA.

in some regions you are likely to see numerous platforms set up to drill for oil from within the sediment strata of the continental shelf. [2] (See illustration 5 in Chapter XVIII discussing pollution.)

Beyond the outer edge of the shelf, starting at depths in the order of 130 m (430 ft), there is a region known as the continental slope, where the depths increase much more rapidly. Even in these deeper waters you may see an occasional platform for drilling for oil, though commercial drilling well beyond the shelf is quite rare. On the other hand, exploratory vessels with bow and stern thrusters for positioning, can drill at increasing depths (Fig. 4). Obviously, it takes a high-powered fathometer to follow the depths beyond the shelf though, many features of this sort can be read as contours on the navigation charts.

Next there is a region known as the continental rise[3] where the depths are still increasing but at a slower rate. Finally, there is the abyssal region—the great ocean depths.

You may notice that the color of the sea tends to change as you travel offshore. At first, shades of green, yellow and other effects associated with these more productive waters may prevail. Then, starting well out onto

2 A ban on drilling in the continental shelf of the United States has been in effect though pumping oil at the platforms where they had already reached appreciable quantities was not curtailed.

3 The term 'rise' may seem a little confusing here inasmuch as you are oriented to progressive depths toward the oceanic abyss.

Fig. 4. Joides Resolution of the Ocean Drilling Program passing through the Panama Canal. This ship deployed 9,200 m (30,000 feet) of drill string and used computer-controlled positioning regulated by 12 thrusters. Joides Resolution is being modernized and will complement the work of a behemoth drill ship built in Japan. Source: The original Ocean Drilling Program.

the continental shelf, the characteristic deep blue of the high seas tends to prevail. As seen from outer space this expanse of blue has given rise to the expression "Blue Planet." Sometimes the transition from the color prevailing near the coast to the extensive blue of the high seas is quite abrupt. (A more thorough discussion of color is included in Chapter IX.)

Early on, when we had only a vague impression as to the nature of the great depths, they might have been regarded as a relatively featureless abyssal plain some 4,000 m (13,000 ft) below the surface. Now, however, we know that the bottom topography of the deep sea is highly irregular and that much of the abyss is a region restless with geophysical activity.

Though a discussion of the great depths may seem beyond the scope of this book which is largely limited to features you can observe at the surface, you will need to understand certain processes that are at work in the great depths in order to interpret your observations. Accordingly, I will discuss some of the highlights of these processes.

Hot molten magma issuing forth from beneath the Earth's crust brings on much of the activity in the bottom of the sea. Created by the upward flow of this magma, there is a continuum of ridges in the ocean basins.

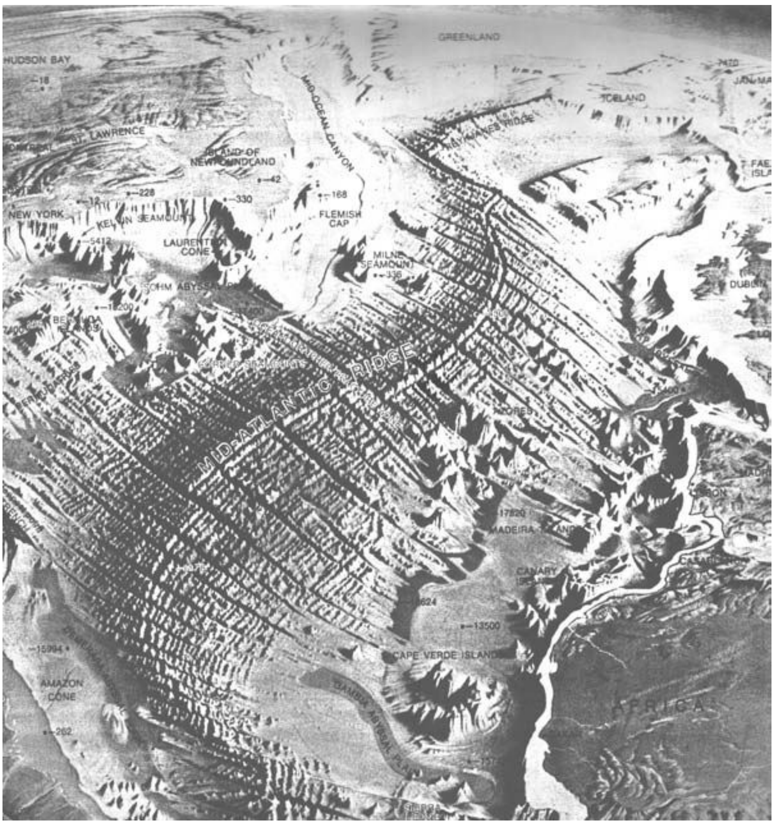


Fig. 5. The Atlantic Ocean is created by spreading from the Mid-Atlantic Ridge. Source: Painting by Heinrich Braun, courtesy of the Aluminum Company of America.

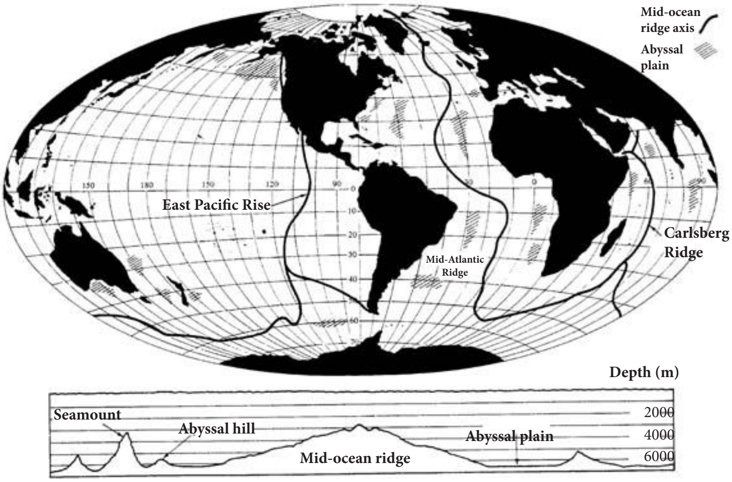


Fig. 6. Mid–ocean ridges and abyssal plains. Source: National Ocean Survey.

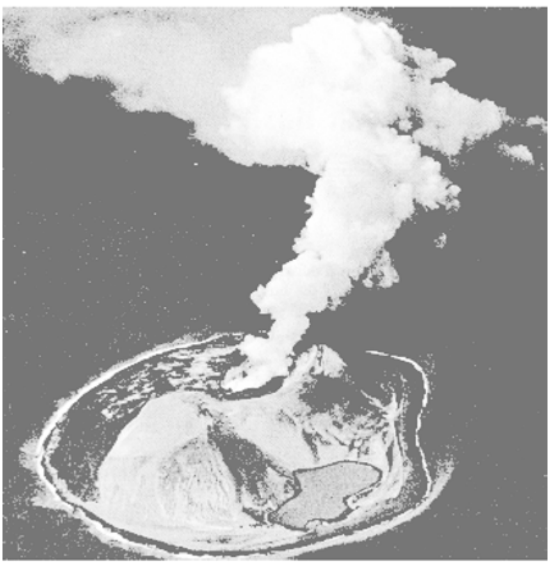


Fig. 7. Surtsey. A classic example of the growth of a new volcanic island from eruptions that began November 14, 1963. Surtsey is located in Iceland at the northern end of the Mid-Atlantic Ridge. Photo on June 18, 1964 by Sigurdur Thorarinsson. Reprinted from Oceanography: An Introduction to the Marine Environment by Peter Weyl. 1970. John Wiley and Sons.

Fig. 8. Harry Hess. As skipper aboard a Navy ship in World War II, Hess took almost continuous echo soundings that revealed deep ocean contours and led to his explanation of sea floor spreading. Source: Department of Geosciences, Princeton University.

Especially impressive is the Mid-Atlantic Ridge from which the Atlantic Ocean originated as the continents spread apart to the east and to the west (Fig. 5-10). Thus, the outlines of the continents on the opposite sides of the Atlantic look as though they could fit together as in a jigsaw puzzle.

One can further understand activity in the abyss by recognizing that the Earth's crust is made up of large tectonic plates. At least twelve major plates are currently recognized. In some cases the movement of these plates forces one of them to be subducted under the plate adjacent to it. The rate of such plate movement may amount to about 2 cm (.8 in) a year,

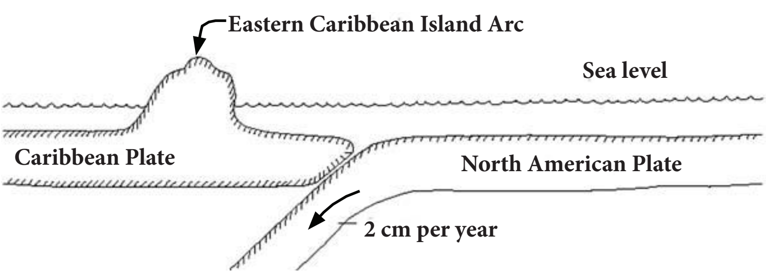


Fig. 9. Diagram of the North American Plate being subducted under the Caribbean Plate.

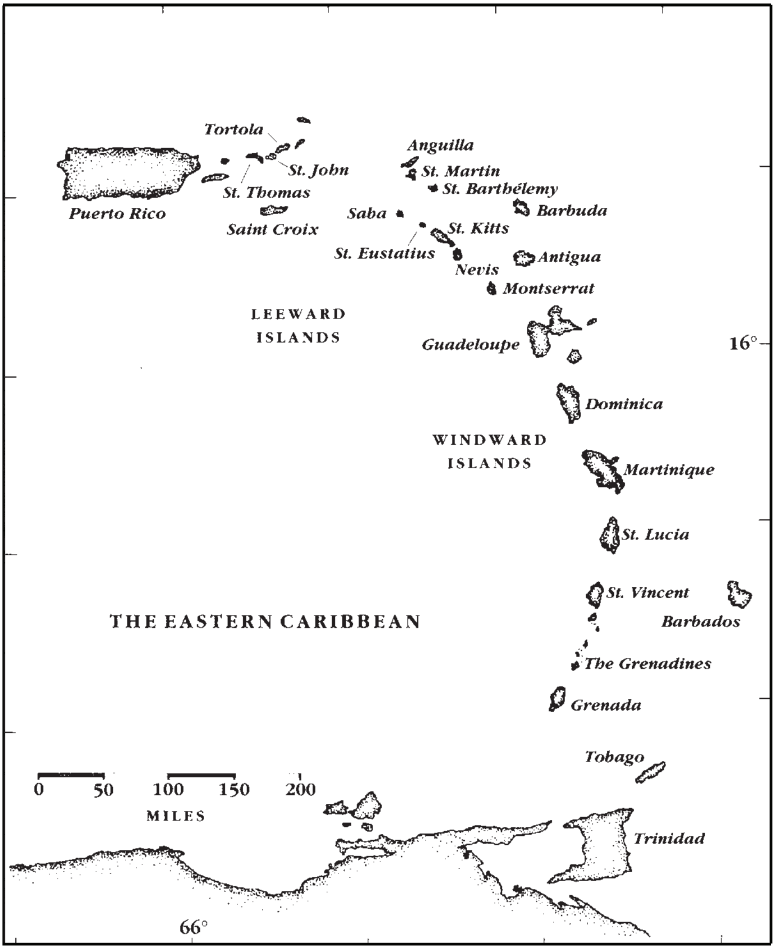


Fig. 10. Volcanic activity due to friction where subduction is taking place has resulted in the Caribbean Island Arc extending from Puerto Rico to Grenada.

being approximately the rate of growth of your fingernails. In some cases, the rate may be higher. Where subduction is taking place, the friction between the plate surfaces often leads to considerable instability resulting in earthquakes, volcanic eruptions, and mountain formations.

Such subduction is well illustrated by the trench just north of Puerto Rico where the North American Plate is sliding under the Caribbean Plate (Fig. 9). Seismic activity continues to the east and south with the Eastern Caribbean island chain being linked to the instability accompanying the subducting plate. Along the chain the volcano on Montserrat is currently active and, far to the south, the subsurface volcano, called Kick 'em Jenny, may soon build sufficiently to form a new island.

The Puerto Rico Trench is very typical of some of the extreme depths that occur along lines of subduction, the deepest being the Mariana Trench where the very large Pacific Plate is being subducted under the Philippine Plate to the west. At 36,152 ft, the depth of this trench is deeper than the height of Mt. Everest at 29,028 ft.

In 1977 Oregon State University led an expedition to search for the source of warm water that seemed to come from outpourings in the sea floor, perhaps from vents between the tectonic plates. They concentrated on the Galapagos Rift west of Ecuador where they found a vent with fluids gushing forth at very high temperatures and with a high sulfur content, all derived from the magma below. Furthermore, they discovered a previously unknown and completely unanticipated community of organisms flourishing in the anoxic (no oxygen condition)

Fig. 11. Life in the deep sea vents was first discovered in 1977 on an expedition organized by Oregon State University. These unknown worms look somewhat like eight-foot tall candles. Photo courtesy of the Woods Hole Oceanographic Institution.

and high temperature surroundings (Fig. 11). It was soon realized that the abundant and unique life in such a setting, which is far below the penetration of the Sun's energy, is sustained by bacteria that metabolize the sulfides concentrated in the outpouring water and the deposits thereof.

Since that first discovery, hundreds of such vents have been found and studied at other plate boundaries and more vents were discovered at other locales where there is similar seepage through the ocean floor and margins thereof. The communities associated with such sites typically have much in common with the unique organisms discovered on the Galapagos Rift. At some of the vents, the outpouring is so rich in sulfides that it is gushing forth through chimney-like deposits referred to as *black smokers*.

Recently, a vent has been discovered that is quite distinct from the rest and is located in the South Atlantic about 15 km (~9.5 mi) west of the Mid Atlantic Ridge. A concentration of calcium carbonate in the outpouring fluids has resulted in spires growing to a height of 60 m (~200 ft). The oceanographers who discovered this referred to it as *The Lost City*.

The temperature of the outpouring fluids is far less than that of the more well-known vents and, whereas the former is characterized by concentrations of sulfur, the fluid of the Lost City vents is rich in methane and energy for the surrounding community may be derived from bacteria that use the methane as a source. While the associated biological community is diverse, biomass is not so good and the species present differ somewhat from those of the sulphur vents. Now that an outpouring of this nature has been discovered and it seems that the processes involved might readily occur elsewhere, it could well be that many more 'Lost Cities' will be found.[4]

In addition to the activity discussed thus far, there are the so-called 'hot spots' where magma has broken through the tectonic plates. The Hawaiian chain that has broken though the Pacific Plate and extends beyond Midway Island is an impressive example. And volcanic activity breaking through tectonic plates is common throughout the Mid- and South Pacific and areas of the Indian Ocean where there are many volcanic islands, atolls, and subsurface sea mounts.

From the foregoing accounts you can sense that there is a great deal

4 This 'Lost City' is not to be confused with accounts, strictly mythological, that cities of the past have become submerged and are yet to be found in the depths of the ocean.

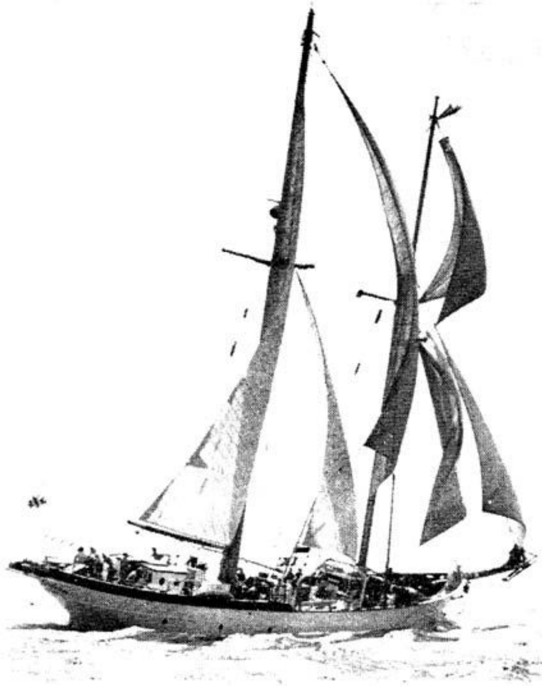


Fig. 12. Westward of the Sea Education Association. In 1987 Westward started to take soundings on Kick 'em Jenny. Observations of the growing volcano were continued until shipping was banned in the area due to the likelihood that a new eruption would break the surface. Source: Sea Education Association.

of activity in the ocean depths and there is more, much more including turbidity currents, underwater slumping, the spread of magma, and canyon formations. All such activity explains why the topography of the oceanic abyss is very rugged.

As I close this chapter I want to say more about Kick 'em Jenny. This is a submerged but rising volcano which, as mentioned, is likely to become a new island, perhaps even before this book is printed. My colleague at the University of Rhode Island, Haraldur Sigurdsson[5], had been interested in Kick 'em Jenny but could not fit it into his program of volcano observations. I agreed to check on itwhen, in 1987, I was able to sail north from Grenada on the Sea Education vessel, *Westward* (Fig. 12).

5 Since Sigurdsson hails from Iceland where, at the northern tip of the Mid-Atlantic ridge, there is considerable volcanic activity, it seems only natural that he has become a volcano expert.

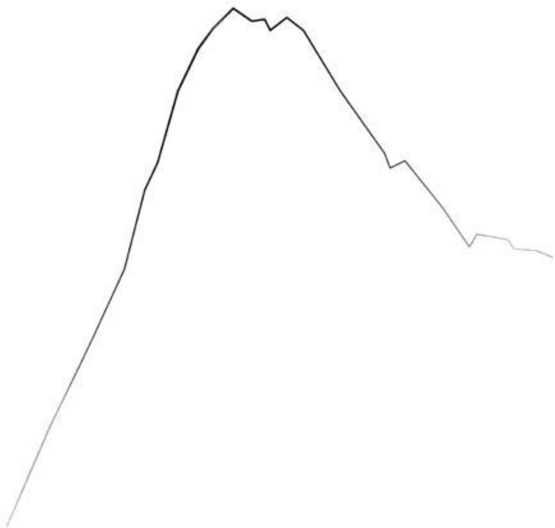


Fig. 13. Profile of Kick 'em Jenny from transit made by the Sea Education Association in December 1999. At the time the peak was recorded at 210 m below the sea surface, a considerable build-up since the first soundings by SEA. Source: Sea Education Association.

The captain and the science crew agreed. We readily found the submerged rim of the volcano and during the next decade and a half the Sea Education (SEA) was very diligent in observing this rising underwater phenomena. Furthermore, SEA had acquired better equipment for sounding, also for sensing the temperature associated with the volcanic activity (Fig. 13).

Recently, with the threat of a dangerous eruption, ships are warned they must give Kick 'em Jenny a wide berth and the SEA has not been given clearance to continue its observations. On the other hand, a multidisciplinary team of experts, with Sigurdsson now involved as chief scientist, was called upon to observe the current seismic activity. This team, including additional participants from the University of Rhode Island, colleagues from the University of the West Indies who had also been watching Kick 'em Jenny over the years, and scientists from the National Oceanographic and Atmospheric Administration, visited the site in March of 2003 on a vessel fully equipped for the task and including a submersible that operated by remote control.

The findings of this new team are exciting. Kick 'em Jenny, though only 150 m (~490 ft) below the surface, was dormant at the time of the observations. Apparently it had erupted below the surface about a year before. The surroundings included deep sea vents with hot, fluid outpourings and their distinct vent communities with species of shrimp and polychaete worms. Furthermore, the team found that there were five additional volcanoes in the immediate area, one of these being quite large.

A volcano of this sort, so near the surface and likely to erupt most any moment, poses a double threat. Obviously there is the damage possible from the force of the blast, but there is also the remote possibility that the volume of gas extruded will decrease the density and associated buoyancy of the overlying water with the result that vessels in the area may founder.

Needless to say, there are scientists elsewhere following the history of seamounts that are building upward from the sea floor. Several groups are involved in maintaining recording instruments and tracking the activity of the Axial Seamount located about 480 km (300 mi) west of Cannon Beach, Oregon. This is the western edge of the Juan de Fuca Plate which, toward the east is being subducted along the Northwest Coast of North America. In 1998 there was a significant eruption in the Axial Seamount but, since the continuing accumulation of magma is only about 5 cm (~2 in) annually and the build-up is about a mile below the surface, the possibility of breaking the surface is not imminent. Vent conditions associated with this region harbor some of the unique communities discussed above in relation to other vent outpourings.

References for Intertidal Zonation:

A Field Guide to the Atlantic Seashore by Gosner, Kenneth L. 1999. The Peterson Field Guide Series. Houghton Mifflin Co., Boston.

Between Pacific Tides by Ricketts, Edward F., Jack Calvin, Joel W. Hedgpeth, Revised by David W. Philips, 5th edition, 1992. Stanford University Press, Stanford, California.

Encyclopedia of Tidepools and Rocky Shores. Edited by Denny and Steven D. Gaines, 2007. University of California Press, Berkely, California.

Chapter III.
Wind-Generated Waves and Breakers

Spend some time just looking at the waves. No matter how long you watch, the patterns are never repeated. They come in many sizes and shapes, ranging from the ripples formed by a light breeze to enormous storm waves several meters high. As waves often come in 'trains' from many different directions, the seas that result may be rather turbulent.

In order to understand the features of a hypothetical 'idealized' wave, you should look for a predominant and regular wave pattern. As just noted, finding this can be a bit difficult unless the wind has been blowing steadily in one direction. Such a wind-driven wave has the dimensions shown in the accompanying sketch (Fig. 1). The crest is the highest point; the trough the lowest. The wave length (L) is the distance from crest to crest or from trough to trough. The height (H) is the vertical distance

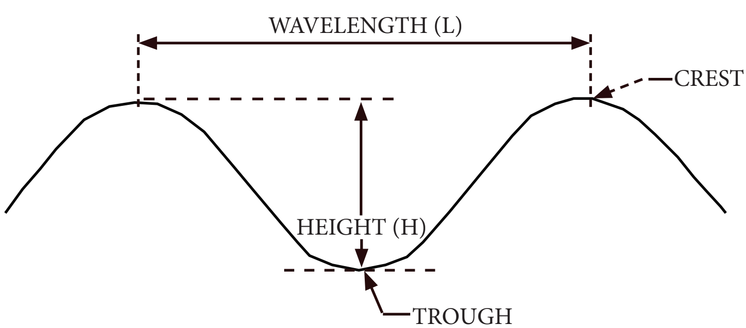


Fig. 1. Characteristics of an 'ideal' wave. Drawing by Debbie Kennedy.

from the trough to the crest. And the period (T) is the time it takes for two consecutive crests or troughs to pass by. Frequency (f) refers to the number of waves that pass by in a given time span. The speed or velocity (C) is the rate at which the wave form is progressing across the surface, being equal to the wave length divided by the period (L/T).

To repeat, these quantities are:

L—wave length **T—wave period**

H—wave height **f—wave frequency= 1/T**

C—wave speed or velocity = L/T.

The force of the wind acting on the surface of the sea results in wind-generated waves. In a light breeze, ripples (technically known as *capillary waves*) begin to develop through the interplay of the friction of the wind on the surface and the counteracting surface tension. The wave length (L) of *capillary waves* is less than 1.7 cm (.68 in) and the period (T) is less than 0.1 second. The ripples provide a rough surface for increasing winds to "grab onto" as they build higher waves. Since higher waves involve the interplay of the friction of the wind and the counteracting gravity, they are known as *gravity waves*.

The wind speed, its duration, and the fetch, namely the unobstructed distance from which the wind is blowing, are the key forces that govern wave development. The accompanying plot shows how these forces interrelate (Fig. 2).

The steepness of the waves is the ratio of the height to the length (H/L) and waves tend to be unstable and break when this is greater than 1/7. New-formed waves are likely to be unstable, as the wave height tends to increase more rapidly than the length. Instability may also develop when opposing currents tend to shorten the wave length or when choppy seas develop from the tide running against the waves. Generally, when the wind continues to blow steadily in one direction, wave length tends to increase and, except for wind-blown spray and some whitecaps, conditions can become rather stable.

The relationship between fetch on the one hand and wave length and height on the other is very important. If the fetch is limited, as in an embayment, the height and length of the waves tend to be limited, even in strong winds. However, with extended fetch, very high, long waves may develop. The resulting high seas and very long waves can have a severe

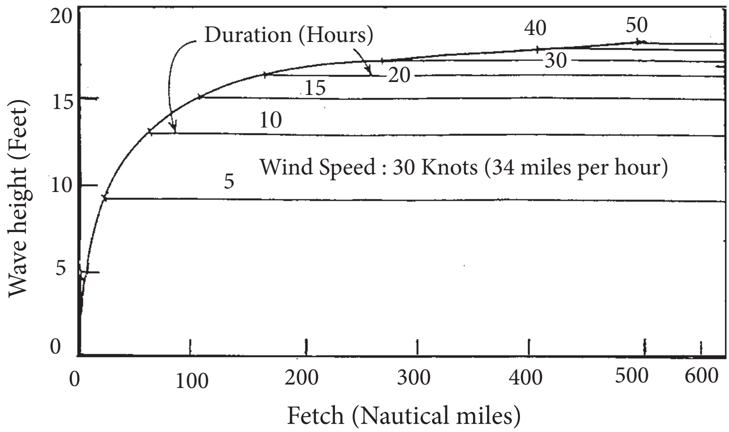


Fig. 2. The diagram shows wave height as it would increase with progressively greater fetch under a given wind of 30 knots (34 mph) continuing for over 50 hours. As winds vary in direction and strength and as some of the effect of the wind may be lost, for example from whitecaps or spray, this is an oversimplification. (Note: On the vertical axis, 10 ft = 3 m; on the horizontal axis, 300 nautical miles is approximately 555 km.)

wrenching effect on large ships, requiring special reinforcement if they are to survive. Thus, if only used on inland waters such as on the Great Lakes of North America where the fetch is limited and the height and particularly the length of the waves are limited, the typical long ships such as the ore carriers, may not need the extra structural strength. (A friend who has served in the Merchant Marine on the Great Lakes does not agree since, in these waters, he has seen first hand how a ship's hull can be strained and twist under the worst conditions.)

You may be wondering how you can determine the height of the waves when at sea. Some suggest, facetiously, that you might come fairly close if you just estimate the top of the crests as best you can, then divide by two to offset the natural tendency to exaggerate. Much is made of a combination of circumstances in which a naval officer, sighting from the bridge of his ship, was able to line-up the wave crests with the boom on the crow's nest. Appropriate calculations indicated a maximum wave height of 34.2 m (113 ft). Though no one claims that these were the largest waves ever, they were spectacular, being equal to the height of a 10 story building. If you should have the opportunity to match this sighting technique, which is quite a challenge from on board a rolling, pitching vessel, even a large one, you too can make some credible measurements of the heights of waves you experience.

As noted, the varied seas that you usually experience are commonly a mix of wave trains that have originated from different directions and under different conditions. When the crests of converging wave trains coincide, very high, steep waves may result. The worst of these conditions are the unusual and often frightening so-called "rogue waves." In the opposite extreme, when the crest of a converging wave coincides with the trough of another, the height is moderated. Obviously all gradations of such interactions occur and, as the lengths of converging waves are seldom the same, there are further complications. You can readily understand why, as repeatedly emphasized herein, the seas tend to be very irregular (Fig. 3).

Fig. 3. A turbulent sea develops where trains of high waves meet after coming from different directions. Source: Woods Hole Oceanographic Institution.

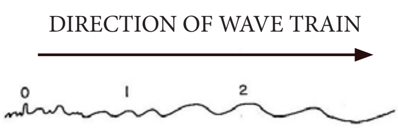
All things considered you can appreciate that the greatest waves on the high seas are to be found where the fetch is almost unlimited and strong winds tend to blow more or less continuously from the same general direction. These conditions are common in the Southern Ocean and sometimes in the North Atlantic and North Pacific.

The following table is a summary of the height of the waves on the oceans of the world:

Location	Percent of total waves of given wave height (m)					
	<1	1-1.5	1.5-2	2-4	4-6.1	>6.1
North Atlantic (Newfoundland to England)	20%	20%	20%	15%	10%	15%
North Pacific (Latitude of Oregon and south of Alaskan Peninsula)	25%	20%	20%	15%	10%	10%
South Pacific (West Wind belt, latitude of Southern Chile)	5%	20%	20%	20%	15%	15%
Southern Indian Ocean (Madagascar and Northern Australia)	35%	25%	20%	15%	5%	5%
Whole Ocean	20%	25%	20%	15%	10%	10%

After Bigelow, H.B. and W.T. Edmonson, 1947. Wind and Waves at Sea, Breakers and Surf. *U.S. Naval Oceanographic Office. H.O. Publ. No. 602. Washington, D.C.*

Since the speed of a wave equals its length divided by the time it takes to pass ($C = L/T$), the longest waves are the fastest and move out ahead as the seas progress downwind. Furthermore, once wave trains are beyond the region where winds are driving them; i.e., once they are moving along of their own momentum, the longer waves become modified as long, more regular *swells* (Fig. 4). If no new forces interfere, such swells may



0 = Choppy sea developed by a storm and becoming weaker further along
1 = Advancing wave group
2 = Swells with longer wave length and greater velocity having outrun the advancing group

Fig. 4. Swells form as the waves of greater length move faster and out ahead of the shorter waves.

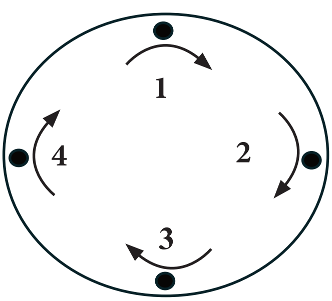
travel across an entire ocean. For instance swells formed off New Zealand have been known to travel all the way to Alaska. If you experience such a swell when anchored in a harbor that is somewhat open to the sea, you must wonder where the distant storm occurred, perhaps many thousands of miles away.

Anemometer records, useful though they are, do not describe the conditions that prevail on the surface of the sea. Sailors may choose either of two descriptive codes for log entries, one being the traditional Beaufort Scale, the other being a listing of sea states. They are combined in the accompanying table.

While the waves driven by the wind progress onward, the water within the waves remains behind. In essence the water in a wave circles in orbits that are about equal in diameter to the height of the wave and this rotation is completed as the wave passes by (Fig. 5). Actually, there is a slight, almost negligible, downwind progression of the orbits primarily because, in real waves at sea, as contrasted with theoretical idealized waves, the troughs are slightly elongated. The orbits decrease exponentially in diameter with depth until, at a depth of about ½ the wave length, they become negligible. Accordingly, a submarine diving to a relatively shallow depth can avoid any wave motion.

If this orbital rotation is unfamiliar or you are a skeptic, try a simple exercise. Throw an orange overboard. Although you see waves passing by, the orange, which remains in the circular orbits of the water, is bobbing up and down and essentially going nowhere.

You can also observe this orbital motion by watching most anything floating within sight, including birds resting and bobbing up and down.



1. Particle in crest of wave
2. Particle descending as the wave moves on.
3. Particle in the trough of the oncoming wave.
4. Particle rising toward the crest of the oncoming wave.

Fig. 5. Orbital motion of a particle in a deep water wave. In contrast to the wave form which is moving onward, the particles remain in place, except for the small progress resulting from the fact that the troughs are slightly elongated.

Beaufort Wind Scale and Sea State Chart

Sea state	Beaufort-number	Terminology	Wind speed (knots)	Description
0	0	Calm	0 - 1	Sea like a mirror
1	1	Light air	1 - 3	Ripples with appearance of scales; no crests
2	2	Light breeze	4 - 6	Small wavelets; crests have glossy appearance but do not break
3	3	Gentle breeze	7 - 10	Large wavelets, crests begin to break; foam of glossy appearance; a few white horses
	4	Moderate breeze	11 - 15	Small waves becoming longer, fairly frequent white horses
4	5	Fresh breeze	16 - 21	Moderate waves taking longer form; many white horses formed; some spray
	6	Strong breeze	22 - 27	Large waves begin to form; many white crests; more spray
5	7	Moderate gale	28 - 33	Sea heaps up; white foam from breaking waves begins to be blown in streaks
	8	Fresh gale	34 - 40	Moderately high waves of greater length; edges of crests begin to break into spindrift; foam blown in well marked streaks; spray affects visibility
6	9	Strong gale (storm)	41 - 47	High waves; dense streaks of foam along wind direction; sea begins to roll; visibility affected
7	10	Whole gale (heavy storm)	48 - 55	Very high waves with long overhanging crests; sea takes white appearance; rolling heavy; visibility affected
8	11	Violent storm	56 - 63	Exceptionally high waves; small and medium-sized ships lost from view; crests blown into froth
9	12	Hurricane	64 & up	Air filled with foam and spray; sea completely white with driving spray; visibility very seriously affected

The Beaufort Scale was introduced by Admiral Francis Beaufort in 1806 to suggest how much sail a fully rigged warship of his day should carry under differing wind velocities.

You can further appreciate the orbital motion at the surface by playing a game of "what if." In other words ask yourself what if the water were moving along with the progress and forward movement of the wave form? Then think how difficult it would be to make progress against a train of waves. You can also appreciate that, inasmuch as the water within the waves is progressing very little, it is only the force of the wind on the hull and rigging, plus any ocean circulation that may be present, that has any major effect on a drifting vessel. This limits the distance lost by a sailing vessel when it heaves to, or either drifts downwind or "lies-a-hull" under bare poles.

From the foregoing you might wonder why it is so desirable to ride the slope from the crests to the troughs of the waves, the so-called surfing tactic that is particularly important in seeking every possible advantage when racing. Essentially this is a matter of coasting on the downhill side of a wave's orbit and gaining extra forward motion from gravity.

Where the water becomes shallow the waves begin to "feel the bottom" and the wave orbits become increasingly elliptical. Once the depth is less than one twentieth of the wave length (L/20), the ellipse is elongated; almost flat, just moving back and forth above the sea floor (Fig. 6). If you are in water shallow and clear enough to see toward the bottom as the orbits have become elliptical, you will notice that the fronds of any vegetation present are swaying back and forth.

Also, as waves approaching the coastline move into shallower water, they slow down. As the speed is decreasing, this causes the waves to become shorter; furthermore, since the overall energy remains the same,

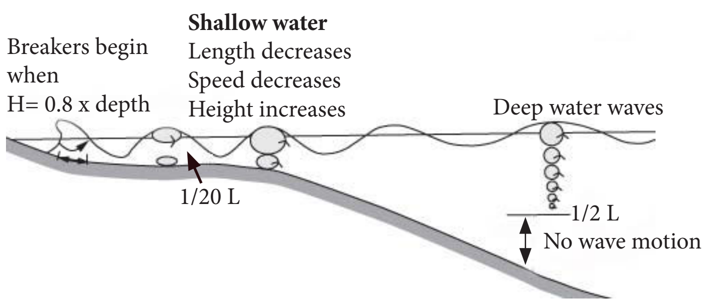


Fig. 6. Orbits of deep water waves decrease in diameter with depth with no motion at depths greater than 1/2 the wave length. In shallow water less than 1/20 the wave length the orbits are elliptical due to drag on the bottom and, as waves continue to decrease in length and speed while increasing in height, they finally break when H=0.8 x depth.

the wave height increases. As the crests continue to move faster than the troughs, the leading edge of the waves becomes very steep. Waves entering shallow water tend to break once the wave height is about 80% of the average water depth. So-called *spilling breakers* occur on relatively flat slopes where the wave height rises slowly and gradually (Fig. 7). The unstable top spills over the front of the wave followed by a long run-up onto the beach. These are the most common breakers (Fig. 8). *Plunging*

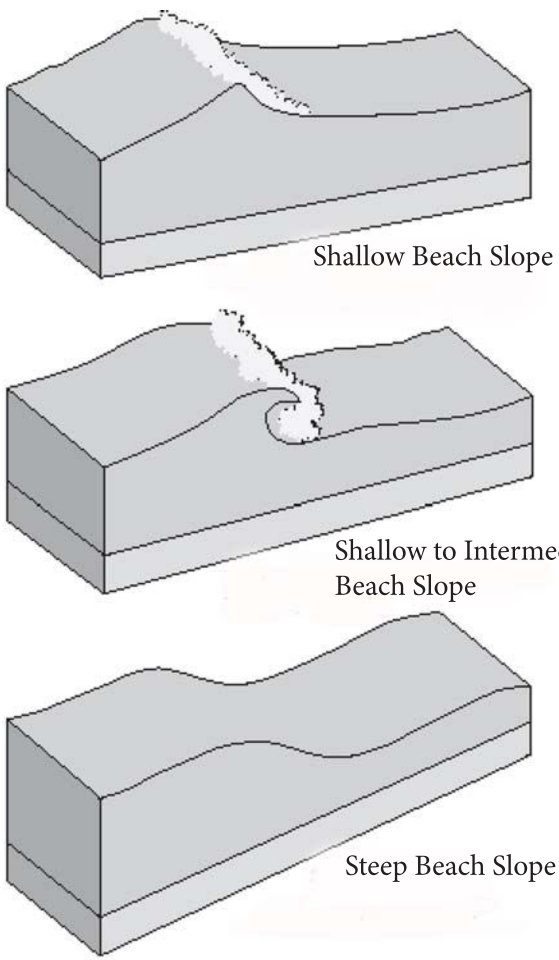


Fig. 7. Types of breakers. Top: spilling breaker; middle: plunging breaker, bottom: surging wave. Modified from Waves, Tides, and Shallow Water Processes from: Open University. Author and publisher.

breakers occur where the beach slope is slightly steeper (Fig. 9). These breakers have a characteristic curling crest looming over a pocket of air.

Waves approaching a shore where bottom contours are steep may not have a chance to break and are reflected back from the coastline. Called *surging waves* they may form a standing wave pattern along the shoreline as discussed in the next chapter.

The nature of the surf may not be as well defined as in the foregoing descriptions since breakers vary due to differences in the contours and slope of the bottom and the height of the waves approaching the coast.

Perhaps something intermediate between the spilling and the plunging breakers best meets the needs of surfers. Also by watching surfers you may learn quite a bit about the *surf zone*. You may see them paddling out beyond the breakers, where the water is deep enough to keep the crests from breaking and where they can just bob up and down on the circular orbits. But they are close to the critical depth where the waves will break and are able to paddle toward shore to catch a good breaker when it occurs. Consciously or otherwise, surfers are sensing and reacting to the wave dynamics discussed herewith.

You have undoubtedly observed that, even though waves may approach the coast at an angle, their crests curve in toward the coast and many advance almost directly toward the shoreline before breaking. This is readily explained since the end of a wave nearest the coast tends to be the first to drag the bottom. Direction is controlled by refraction, as this is called, and it proves to be very effective even to the point of causing waves to roll ashore on a lee coast (Fig. 10).

When the waves are high, refraction can cause the breaking crest to move along more or less parallel to the shore as a sort of curling breaker or tube as the surfers call it. Riding a giant tube can be the ultimate thrill for the truly advanced surfer.

With the water from breakers flowing on and along the shore, it follows that somewhere it must return out to sea. Thus, every so often along the beach the flow turns abruptly offshore as a so-called *rip current* (Fig. 11). Such a current, sometimes mistakenly referred to as undertow, is a serious threat to any swimmer who, in panic, tries to buck the flow. Those who understand the nature of rip currents and who deal with them calmly, know that it is relatively easy to swim in a direction parallel to the beach without attempting to head for shore until free of the outward flow.

Conditions can be quite troublesome when you are nearing the

Fig. 8. Spilling breakers along the beach at Newport, Oregon. Photo by David Griffiths.

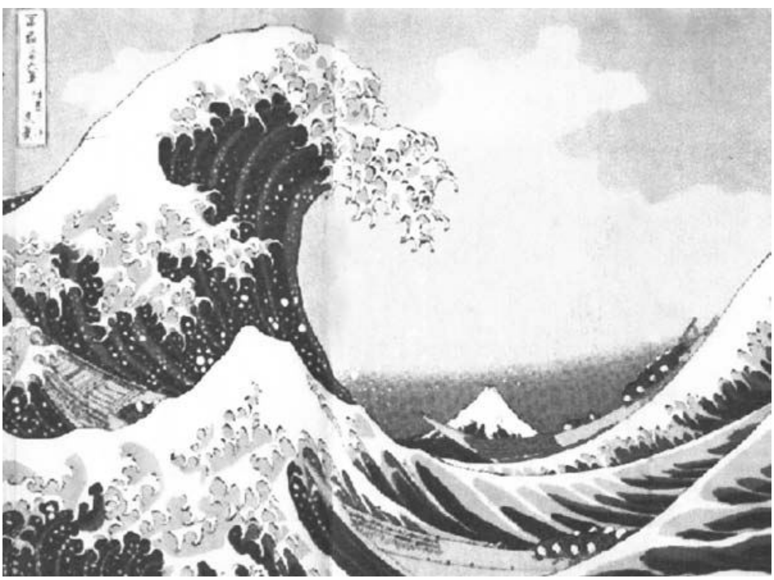


Fig. 9. The classic illustration of a steep plunging wave. This is from a woodblock by the Japanese artist Katsushika Hokusai and is titled Breaking Waves Off Kanagawa. *As portrayed the lead wave is about to form a tube.*

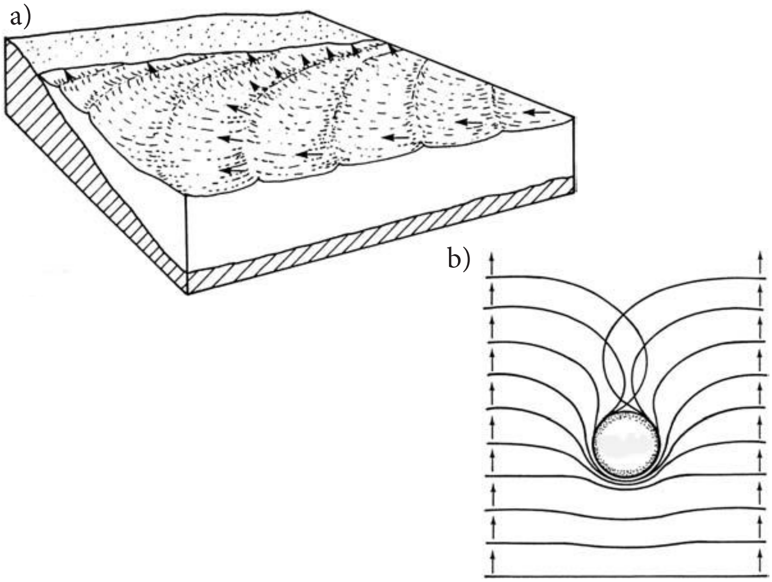


Fig. 10. Refraction (a) toward the beach and (b) around an island as waves drag the bottom in the shallow water closer to shore. Drawings by Debbie Kennedy.

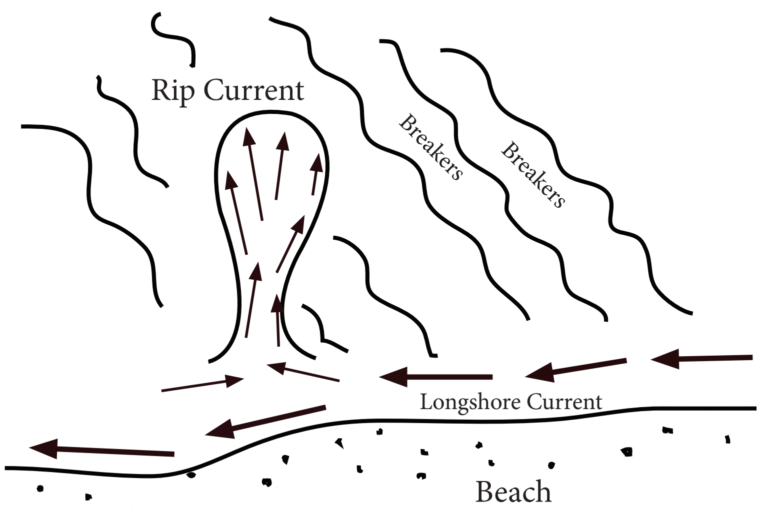


Fig. 11. Rip current.

coast. There is always the risk of running aground in the shallows. The increasing wave height and accompanying wave steepness can be dangerous. Breaking waves with volumes of water rushing toward the shore make it very difficult to maneuver back out to sea, especially under sail and with the wind blowing onshore. Also, off the mouth of an estuary, where tidal ebb currents sometimes buck the incoming waves, surface conditions can be very rough. All things considered you can appreciate why experienced sailors try to stay well off the coast. The call to "head for deep water" often applies.

The world renowned hazardous conditions off the mouth of the Columbia River along the Northwest Coast of the United States vividly illustrate some of the features just discussed. Waves of great length, either as swells approaching under the unlimited fetch of the Pacific or high waves generated by strong regional winds, begin to feel the bottom well offshore where extensive shoals have formed due to sediment carried out of the River. So there are increasing crests and breakers even beyond the jetties, with conditions being especially difficult when the ebb flow out of the estuary is bucking wind-driven waves moving toward the coast. That some early explorers seemed to have completely missed the mouth of the Columbia River may be attributed to these difficult conditions (Fig. 12).

Can waves become dangerous? Of course they can! And the answer involves wave theory, anecdotal evidence, experience, speculation, and the mysteries surrounding those vessels that never returned. Needless to say this is a difficult subject to cover adequately.

Let's start by considering sailing vessels of less than 15 or 20 m (50 or 65 ft) in length, (i.e., small enough to ride up and down on long waves). If such boats are well designed and strongly built, it may be argued that they can take anything the sea has to offer, or so it may be said until circumstances prove otherwise. It is also said that a well-found boat can often take the threatening seas when those on board cannot. I read of one case in which the Coast Guard, judging that a sailboat was about to founder, made a daring helicopter rescue of the three who were on board, yet afterwards the boat was found on a beach in surprisingly good shape. No doubt there are other examples of this sort.

If you are in a small sailing craft under extreme storm conditions the basic choices are to run with the waves under bare poles, to lie-a-hull under bare poles, or to heave-to. Running with the waves involves slowing the boat, usually by dragging warps of some sort, while trying to keep the

Fig. 12. U.S. Coast Guard rescue craft powers through the breaking waves where the ebb current meets the incoming waves such as at the mouth of the Columbia River in the Northwest of the United States. Source: NOAA.

stern into the oncoming waves. Lately, however, sailors have been opting for a technique that might be described as 'let her go,' trying as best possible to ride down the crests in front of the waves, essentially surfing on a grand scale. If this is done at a slight angle, the problem of the bow diving into the crest ahead may be avoided. This technique places a heavy demand on the person at the helm since there is no easy way to keep the boat from laying broadside to the waves, a very precarious position to say the least. Finally, a sea anchor, a large parachute-like rig that may hold the bow or stern into the oncoming waves, may be used.

Obviously there is little or no time to try these different tactics when conditions are rapidly deteriorating. Being as well prepared as possible is undoubtedly the best rule. Practicing these various techniques under less than severe storm conditions is the approach I have used.

No matter what tactics are used there is always the possibility that a small boat will either be pitch-poled or rolled over. Accounts of such happenings seem to indicate that, if a boat is basically strong and everything is well battened down, a well designed monohull (not a cat or trimaran[1]) is bound to right itself. This must be a terrifying experience but the stories of both boat and crew recovering, though not unique, are sometimes hard to believe. Fortunately, the extreme wave effects causing a boat to roll over or pitch pole are not likely to follow one right after another. If this were the case, the recovery stories would be even more incredible.

Such practices as lying-a-hull and running under bare poles can apply to larger sailing vessels as well and, from sheer size, they might fare reasonably well under storm conditions. However, when a vessel is too long to comfortably ride up and down the waves, it may take a terrific beating.

Vessels under power, whether large or small and including sailing craft that have ample auxiliary motors, obviously have more options in threatening seas as they can maneuver and regulate their speed to see what works best. Powering into the waves at a moderate but not a crashing speed is one option that might work very well for a small craft with power. Large ships are more likely to stay on course after slowing down appreciably. Of course, if such a vessel loses power or is otherwise disabled, it becomes very much at the mercy of the storm.

Obviously for all vessels, large or small, powered or rigged for sailing, it is desirable to maneuver to avoid or at least to minimize the crashing impact of tons of water associated with high, turbulent seas. Probably few vessels could survive if battered by a giant avalanche made up of the entire wall of an extremely high sea but it is dangerous enough when, as usually happens, only the uppermost part of the crest slams into the hull. This is where the construction of a vessel, including provisions to batten down, becomes extremely important.

Finally, it is fascinating to look at maps or charts decorated to show the accumulation of shipwrecks through the years. It makes you wonder how it all happened. You will quickly realize that there is quite a bit of

1 Some sailors do sail catamarans and trimarans knowing very well that if flipped over, the boat cannot be righted. One may sit on the overturned hull and hope to be rescued. It remains possible that some sort of buoyancy high on the mast may keep such a boat from being completely overturned.

oceanography involved such as dangerous current patterns, shoal areas subject to dangerous breakers, regions subject to extreme winds, etc. You will readily see that many of the wrecks were relatively large sailing vessels, probably heavily laden and probably difficult to maneuver to stay clear of treacherous conditions.

Chapter IV.
More on Waves

Observations Relating to Standing Waves

From the accompanying sketch you can see that a standing wave involves water rocking back and forth with a node of no up and down motion in between the highs and the lows (Fig. 1). This oscillation is the same as you would see if you were sloshing water back and forth in a pan. *Surging waves* and *seiches* form standing waves; also the tides on the high seas can form modified standing waves.

Surging waves (a type of standing wave)

As noted in the previous chapter where breakers are discussed and illustrated, some waves do not break but become *surging waves* as they roll up against a sea wall, a rocky headland, or a sufficiently steep shoreline. Since the backwash involved often creates confused choppy conditions, observing this wave action can be a bit difficult.

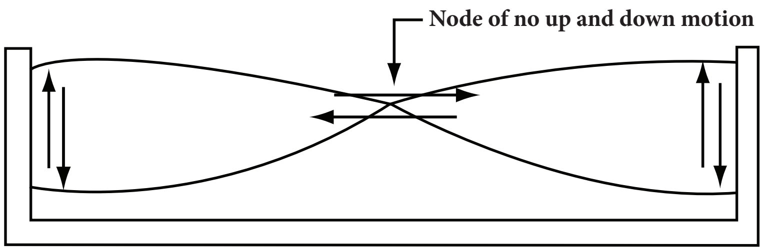


Fig. 1. Diagrammatic representation of a standing wave.

Seiches (a standing wave quite frequent in large basins such as lakes)

You might experience a seiche on a large lake. The effect may occur in a large harbor or a broad lagoon, though the tide might predominate if open to the sea. A seiche commonly gets started when the difference in atmospheric pressure coupled with the resulting wind, causes the water to pile up at one end of an enclosed body of water while draining it from the opposite end. As gravity takes over, the flow oscillates back and forth with each high being succeeded by low water. The alternating high and low water levels set up in this way may continue for a short while after the force driving the seiche no longer exists.

During summers spent on Gibraltar Island near the west end of Lake Erie, I noticed that seiches commonly developed along the long axis of the Lake. What we would see might have been mistaken for low and high tides had we not known that tidal effects are minimal on such enclosed waters. Furthermore, since the timing of the alternating highs and lows did not match any tidal regimes, it became evident that the oscillations tended to be synchronized with the natural rhythm of the length of the lake.

Tide Waves on the High Seas (to be discussed in Chapter VII on tides)

On the high seas, the tide waves circling the planet (due to gravitation involving the Moon, the Sun, and the Earth) are often reflected off the rise and slope of a continental margin; after which they may swing back across the ocean to the opposite continent. The standing waves that result curve in response to the Coriolis Effect (described in the next chapter) and rotate around what are known as amphridromic points where there is no motion. Amphidromic points are analogues to the nodes of no motion of a simple standing wave. Such wave features are discussed and illustrated further in Chapter VII focusing on tides.

Tsunamis or Seismic Sea Waves (often incorrectly referred to as Tidal Waves)

When I was writing this we experienced what was, by far, the most devastating tsunami on record, perhaps the worst natural disaster ever experienced by humans. On December 26, 2004 one of the strongest

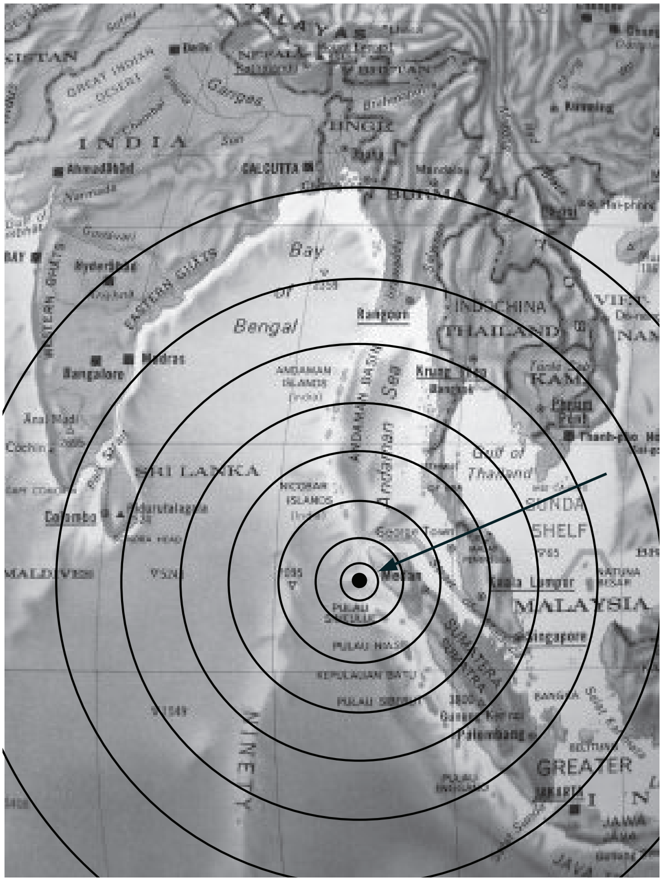


Fig. 2. Areas in southeast Asia, most notably Sumatra, Sri Lanka, southeast India, Phuket, Northern Malaysia, and the Maldive Islands suffered extreme devastation from the Asian tsunami originating from an earthquake on Dec. 26, 2004 off the Northwest Coast of Sumatra. See arrow indicating the epicenter of the quake and the concentric rings indicating the outward movement from the center.

earthquakes on record (9.3 on the Richter Scale) shook the sea floor along a fault just west of the northern tip of Sumatra in Indonesia.[1] This resulted in a tsunami so destructive that almost all structures in the low-lying areas were totally demolished in Aceh and other regions of Sumatra (Fig. 2). Other areas affected were in Sri Lanka, Southeast India, Phuket,

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1 In the years following, there have been further significant earthquakes and some tsunami damage along the extended fault line.

Fig. 3. Typical scene in Aceh after the Asian tsunami. Source: U.S. Navy.

Fig. 4. Helicopters bring relief supplies to areas in Sumatra that were not accessible by any other means after the tsunami. Source: U.S. Navy.

northwestern sites in Malaysia, and areas across the Maldive Islands. Far worse was the death toll and number of people missing who may never be completely accounted for. In Aceh alone one count indicates that over 100,000 lives were lost, mostly due to drowning (Fig. 3, 4). With additional drownings and death from injuries and waterborne diseases, the total lives lost in the areas of the Indian Ocean lying in the path of this tsunami is said to have amounted to 250,000. By comparison, this is many times the approximately 40,000 people that drowned when the Indonesian volcano, Krakatoa, erupted in August 1883, shook the adjacent coastal area, and resulted in a tsunami that previously had been regarded as the most disastrous in the historical record.

To understand the nature of a tsunami, think of a jolt of some sort occurring underwater, perhaps as the result of an earthquake along a fault line, from volcanic activity, from a massive slump in the seabed, or even from a meteorite. Such a jolt might send a wave crest not much more than a foot high circling outward in concentric directions at speeds in excess of 460 mph (740 km/h). There are often successive crests following as much as 30 m apart and moving with much the same velocity.

Though the speed of such a seismic wave is sufficient to cross an entire ocean, even the wide Pacific, in one day, you are not likely to notice the low crest as it passes on the high seas. As it moves into shallow water and as the bottom topography rises, the wave slows down and its height increases. It's all a matter of proportions. The total energy is still there but the reduced speed is converted into wave height. On a much grander scale it's the same as the effect we observe when wind-driven waves break as they approach the shore. Furthermore, as the heightened wave crest of a tsunami approaches the coast, it may be preceded by extremely low water corresponding to the trough of this unique wave form.

The height and mass of a tsunami wave coming ashore are commonly greater than the dimensions of the breakers of the largest of the wind-driven waves. Thus, a tsunami wave, breaking and crashing along the coast, perhaps moving 25 knots (30 mph) as an enormous and turbulent wall of water is the most destructive of all wave-related impacts. Its effect is exacerbated by the wreckage it carries.

In the century past our awareness of tsunamis was heightened when, on April 1, 1946, an earthquake in the Aleutian chain in Alaska resulted in a surprise tsunami crashing ashore five hours later in Hilo, Hawaii. In this case, the extreme low water that preceded the crest fooled the local people who dashed out to do some "'gleaning" on what they thought was nothing other than an unusually low tide. Around 150 drowned when the wave crest followed.

Hilo and other sites around the Pacific have continued to be on the disaster end of a number of tsunamis and, though none has been nearly as damaging as the recent tragic Asian event of December 2004, several have resulted in considerable loss of life where they went ashore. A strong earthquake off the Southern Coast of Chile on May 1960 caused what was perhaps the worst tsunami of the twentieth century. As it circled onward and outward it did considerable damage to coastal sites in South and North America. In Crescent City, California, the tsunami was about 2 m (~6.5 ft) high as it flooded the area. Estimated drownings from this 1960 event include hundreds in Chile, some 60 in Hawaii, and well over 100 in Japan. The impact in Japan from a quake known to have occurred off Chile is a clear reminder of the way in which tsunamis progress in concentric circles from wherever they originate.[2] If you toss a small rock in a pond, the ripples provide a small scale demonstration of this circling effect.

After our awakening experience in Hilo in 1946, it was realized that, because volcanoes and earthquakes are so common around the rim of the Pacific, referred to as The Ring of Fire, ocean-wide warning provisions were needed and an International Tsunami Warning Program was soon taking shape in order to observe the origin, course, speed and travel time of seismic waves traveling across the surface of the sea (Fig. 5). However, attaining a reliable warning system free of false alarms has been difficult partly because even some large seismic shocks do not result in tsunamis. Recently, sensors placed on the bottom of the ocean capable of detecting the seismic pressure above and relaying it to buoys on the surface, help to differentiate between the false alarms and the real threats. Now, there is a move to place an adequate array of these tsunameters world-wide as well as around the Pacific.

Though, with such sensors, we should be more confident that warnings of tsunamis originating from far away will be available and false alarms will be avoided, this does not address the fact that waves originating just

2 Japan, being unusually vulnerable to earthquake and seismic activity in general, has been subjected to numerous tsunamis and the word *tsunami* is of Japanese derivation. Along some vulnerable coastal areas, the Japanese have constructed enormous, gated dikes as a defense against tsunami damage.

The Pacific Ocean Ring of Fire

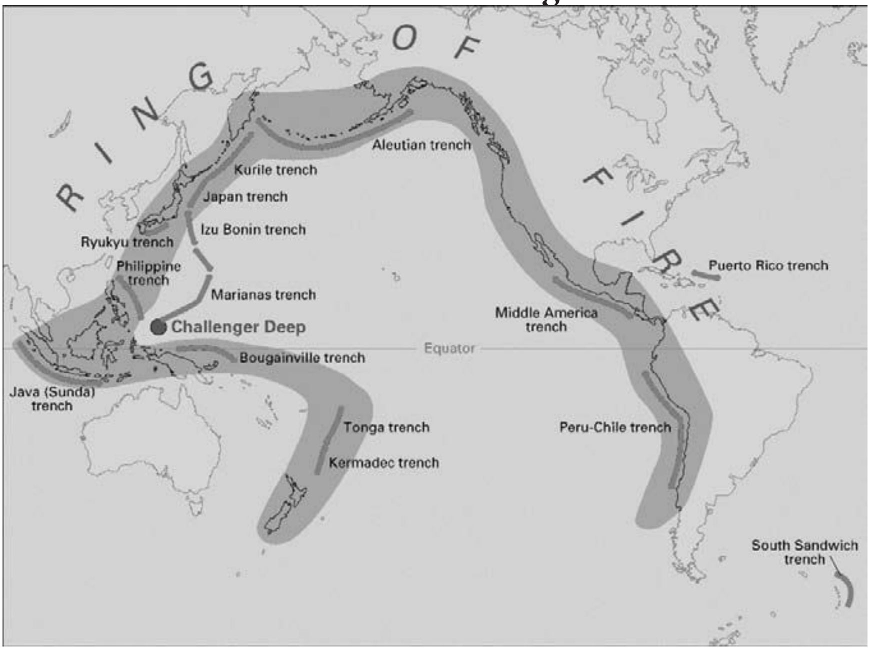


Fig. 5. The Ring of Fire around the Pacific Ocean. The shading indicates the area subject to considerable volcanic and earthquake activity. Source: U.S. Geological Survey.

off any given coastal area may arrive with very little notice. This happened recently in Japan where there was only a 10 minute advanced warning. It happened off Papua New Guinea in 1998 where an underwater slippage event only 32 km (20 mi) off the coast resulted in a tsunami that caught the natives by surprise and some 3,000 people drowned.

There is a very real possibility that something just as disastrous could occur along the West Coast of North America from California to Southern British Columbia where tectonic plates are being subducted under the continent. Actually on June 14, 2005, a 7.0 earthquake shook the ocean bottom 145 km (90 mi) off Northern California, triggering tsunami warnings from Southern California to the Washington coast. The disruption was in an area of convergence on the North America Plate, the extensive plate across the entire Pacific, and the Juan de Fuca Plate generally centered off Oregon. It was subsequently determined that this disruption was what geologists refer to as a strike-slip event with the

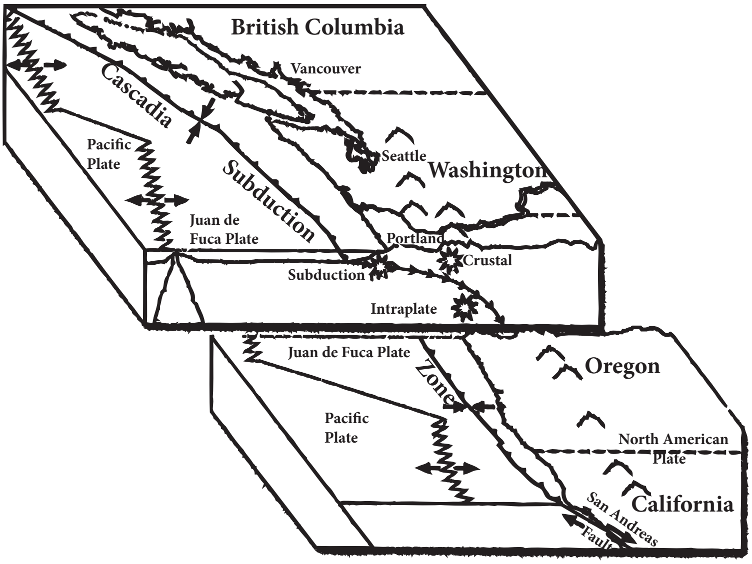


Fig. 6. Subduction of the Juan de Fuca Plate under the Continental Plate along the coast of Oregon, Washington, and British Columbia. Source: Oregon Department of Geology and Mineral Industries.

motion in the sea bed being horizontal, not the vertical displacement that typically leads to a tsunami. So, though a tsunami did not develop, it made the residents realize the imminent danger of such waves.

This danger, as it involves the Juan de Fuca Plate, is apparent from the accompanying illustration of the subduction under the continental plate causing friction that has resulted in the volcanic Cascade Mountains not far inland and explaining the relative frequency of earthquakes in the region (Fig. 6). Should one of the major earthquakes of this convergence occur only 50 km (30 mi) or so off the coast with a tsunami as a result, those in the area might have no more than 10 minutes before the first crest reached the shore. It's simply a matter of the short distance and the high speed of the waves. In many coastal areas signs advise the public as to the routes to take to reach safe high ground in the event of a tsunami alarm but there may not be sufficient time between the warning and the arrival of destructive waves to avoid disaster (Fig. 7).

No coastal region is completely free of such a threat and the East Coast of North America, though subject to relatively little seismic activity, is no exception. For instance, in 1929 there was a tsunami wave in Placentia

Fig. 7. Signs like this indicate escape routes in the event of a tsunami warning.

Fig. 8. Eruption in 1980 of Mount St. Helens, an active volcano of the Cascade Range. Source: U.S. Geological Survey.

Bay, Newfoundland, with considerable loss of life. Puerto Rico seems quite vulnerable because, immediately to the north, there is the second deepest trench in the world where, as mentioned in Chapter II, the North American Plate is dipping under the Caribbean Plate. A 7.8 earthquake there in 1918 caused a tsunami and 40 people drowned.

What a scary outlook! If there is any basis for optimism, and this is questionable, it lies in the realm of probabilities, i.e., when will the next disaster occur and how bad will it be? So, what are the probabilities? For the Pacific, where 80% of the tsunamis occur, one analysis suggests that a tsunami with a wave height of more than 7.5 m (~25 ft) would occur once in every 15 years. Predicting just when, where, and how dangerous this might be is as difficult as predicting other seismic events such as earthquakes on land or the eruptions of volcanoes (Fig. 8). To anticipate a tsunami may be more difficult since the origin is underwater.

Storm surges (not to be confused with surging waves)

As already mentioned in discussing the origin of a seiche, you may notice that the water level driven by high winds, can rise higher than usual. Ordinarily there is little or no damage as a result. However, when the

Fig. 9. Surge damage in Galveston, Texas from a hurricane in 1900. Prior to the extreme destruction and loss of life accompanying Hurricane Katrina in 2005, this was often referred to as the worst natural disaster in the history of the United States as some 8,000 people drowned when the storm surge swept over the island. Source: NOAA.

winds are very strong and there is considerable fetch, a storm surge can flood and do a great deal of damage to a coastal area, particularly if it arrives at the time of normal high tide.

Those living along coastal areas of the Gulf of Mexico had become aware of and had experienced numerous surges due to the frequency with which hurricanes approach from a long fetch across the Gulf. They had not forgotten the 1900 storm when water swept over the city of Galveston, Texas, built on a low lying island, and 8,000 people, perhaps more, drowned (Fig. 9). This has been referred to as the worst natural disaster in U.S. history. The surge from Hurricane Ike which swamped Galveston in 1907 was every bit as bad but without resulting in a heavy loss of life as good warnings were in effect. As you will undoubtably recall this followed. Hurricane Katrina, with a surge that flooded New Orleans in 2005 and had been extremely disastrous in terms of displaced persons and the need for reconstruction.

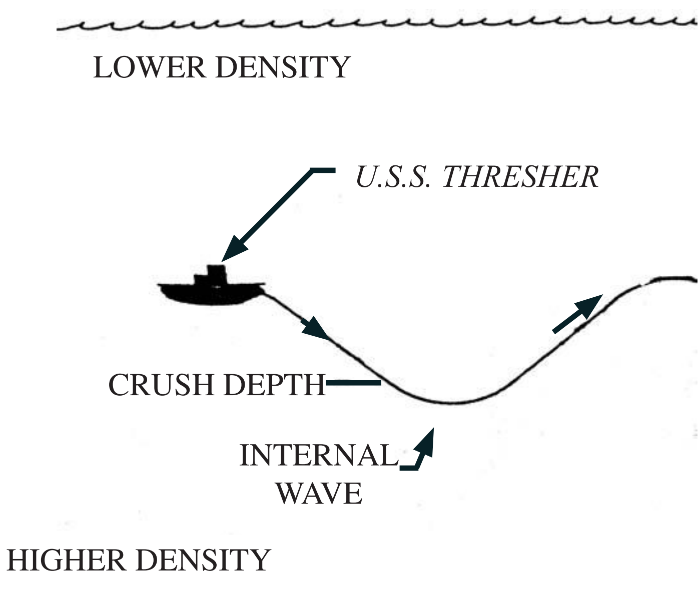


Fig. 10. Diagram of a hypothetical scenario suggesting that an internal wave had taken the nuclear submarine U.S.S. Thresher to depths greater than its hull could withstand. The internal wave may explain the loss of the Thresher off the coast of New England in 1963.

Internal waves

Internal waves bear some similarities to wind-generated waves except that, instead of involving a water to air interface, an internal wave develops at the boundaries of waters of different densities. Suggestions as to their origin include tidal forces, seismic activity, and possibly some little-understood wind effects. Sometimes there are surface effects which may be indicative of the wave movement below (Fig 10).

Episodic waves

In addition to the very high waves discussed in the previous chapter, some experts suggest that an even more dangerous wave form, referred to as episodic waves, should be recognized. A region off the East Coast of Africa where currents traveling north from the Southern Ocean run into the south-flowing Agulhas Current is often cited in discussions as to where such waves might occur. Here there may be unusually short waves running as high as 30 m (100 ft). It could be that, though large ocean-going ships may be especially reinforced to withstand most any waves encountered on the high seas, this unique combination of short waves of extreme height, leads to some of the mysterious ship losses.

Langmuir Circulation

As you look downwind under light winds and a relatively smooth sea, you may see long rows where anything drifting on the surface has tended to accumulate. To understand these rows of convergence, you must visualize a cross section just below the surface as shown in the accompanying figure portraying Langmuir Circulation (Fig. 11).

This is a phenomenon in which subsurface cells of divergence and convergence progress downwind in opposing corkscrew rotations that are developed and driven by the wind. These vortices are important in a number of ways, perhaps most notably as they affect the distribution of microscopic plant life and various larval stages. In an accompanying diagram, you can see how foam on the ocean surface may become oriented along the lines of convergence (Fig. 12). Incidentally such foam, looking somewhat like shaving cream at a distance, can be a sign of healthy conditions, being derived from naturally produced organic matter.

We applied the Langmuir Circulation effect when we were sampling for the larval stages of the lobsters off Southern New England. Our field

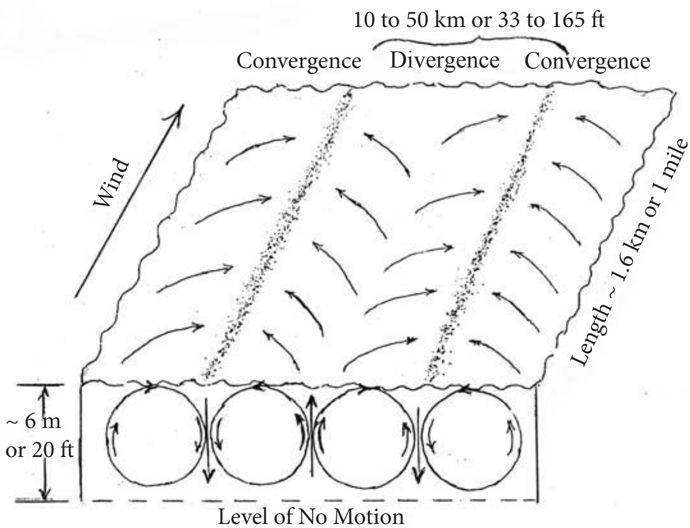


Fig. 11. Langmuir Circulation: Steady winds blowing across the ocean surface may create convection cells of alternate right- and left-handed rotation. Lines of convergence may produce windrows of accumulating plankton and organic debris.

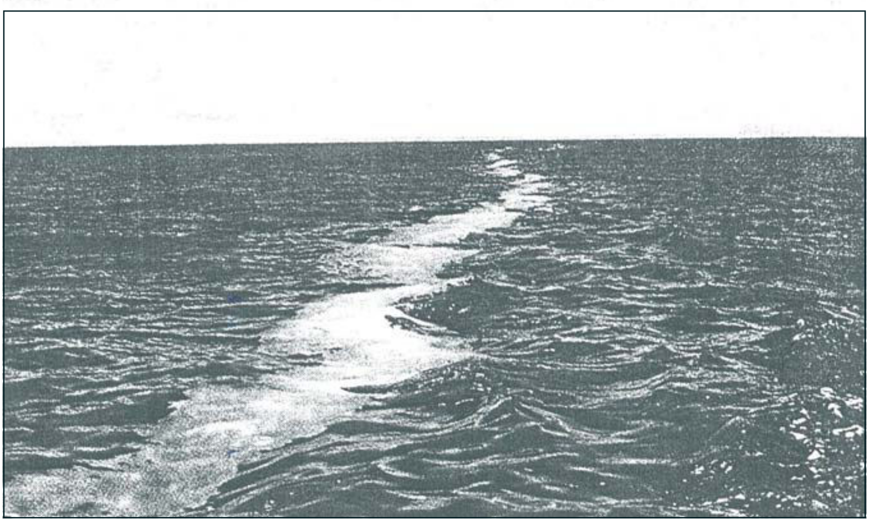


Fig. 12. Foam along the lines of convergence of Langmuir Circulation. Source: Open University. Author and publisher.

team had been unable to obtain the larvae in our sampling tows until we discovered that they tend to become concentrated along the lines of convergence. (Further information with respect to Langmuir Circulation is presented in Chapter XI as it relates to the sailing of the Portuguese-Man-o-War and the By-the-Wind-Sailor.)

General comments on surface effects

As a rule surface waters are rather well mixed. Yet, in sampling for nutrients and plankton, localized, patchy distributions are commonly encountered. In addition to this patchiness, broad areas of the surface may at times appear distinct and separate. Some of these effects may reflect conditions beneath the surface. Once the wind stirs the ocean surface, however, it becomes well mixed, or at least any lack of mixing becomes less evident.

Chapter V.
The Coriolis Effect and the Ekman Spiral

The Coriolis Effect causes currents and the winds to curve off to the right in the Northern Hemisphere and off to the left in the Southern Hemisphere. This is one of the first things oceanography students are taught and you will appreciate why as you continue to interpret your observations.

The Coriolis Effect is really quite easy to understand (Fig. 1). If you were standing on the Equator you would be moving eastward at the speed of the Earth's daily rotation, i.e., ~1670 km/hr (1050 mph). By contrast, if you were standing at either the North or the South Pole, you would not be advancing eastward though an eastward rotation is taking place in the adjacent latitude. Due to these differences, an ocean current flowing or the wind blowing from the Equator toward either pole is moving faster than the surroundings, i.e., off to the right in the Northern Hemisphere and off to the left in the Southern Hemisphere. Any movement from either pole toward the Equator is going slower than the surroundings, also to the right and left in the Northern and Southern Hemispheres respectively. The effect is greater in the polar regions than in the low latitudes.

If you want a neat demonstration and have an old fashion phonograph available, place something in the center of the turntable and rotate a record as slowly as possible so you can watch what will happen. Then slide or roll the item from the center toward the outer edge of the record and note how it falls behind. In this exercise the center of the record represents simulates the South Pole and the rim of the record represents the Equator. If it were possible to reverse the rotation of the turntable, you

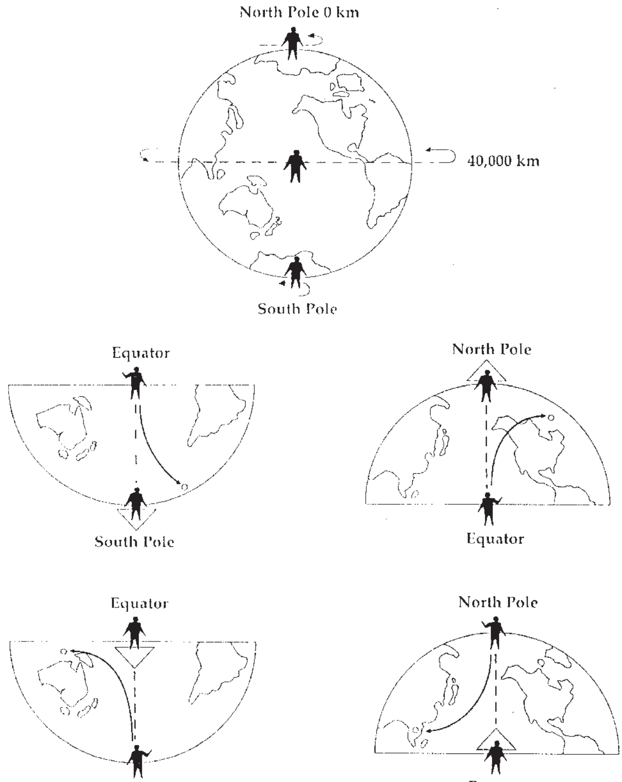


Fig. 1. The Coriolis Effect. The top sketch shows the distance traveled due to the rotation of the Earth. For instance at the Equator this amounts to 40,000 km in 24 hrs, or more than 1,000 mph. A lower sketch on the right shows that, if you are traveling due north from the Equator toward the North Pole, let's say in an airplane in which the pilot has not corrected for the Coriolis Effect, your plane will be carried off to the right because your speed on the Equator is faster than that at progressively higher latitudes. The remaining sketches indicate being carried off to the right if traveling from the North Pole toward the Equator and being carried off to the left if traveling in the Southern Hemisphere. Source: Coastal Zones of the Pacific. A Descriptive Atlas. *1966.*

would see that the deflection of the sliding object is reversed with the hub of the record simulating the North Pole.

Now we come to the Ekman Spiral (Fig. 2). The Coriolis Effect is, of course, affecting both the wind direction and that of the water surface below. And the latter, being comparatively dense and slow to respond, is deflected some 45˚ from the direction of the wind. Furthermore, as the speed of the current beneath the surface decreases with depth while the Coriolis Effect is ever-present, the current at great depths, though moving very slowly, ultimately flows in a direction opposite to that at the surface. Barring other influences that may modify the water column, the mass transport due to the Ekman Spiral is 90˚ to the right of the surface current in the Northern Hemisphere and 90˚ to the left in the Southern Hemisphere.

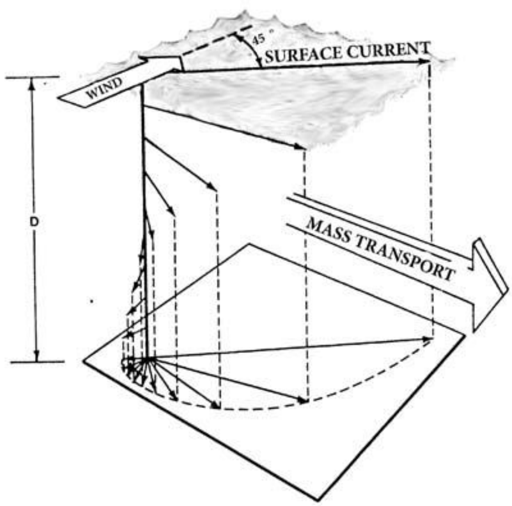


Fig. 2. Diagram of the Ekman Spiral. Source: Williams, Jerome, John J. Higginson and John D. Rohrbough, 1968. Sea and Air: the Naval Environment. *United States Naval Institute, Annapolis, MD.*

Chapter VI.
Wind-Driven Surface Circulation

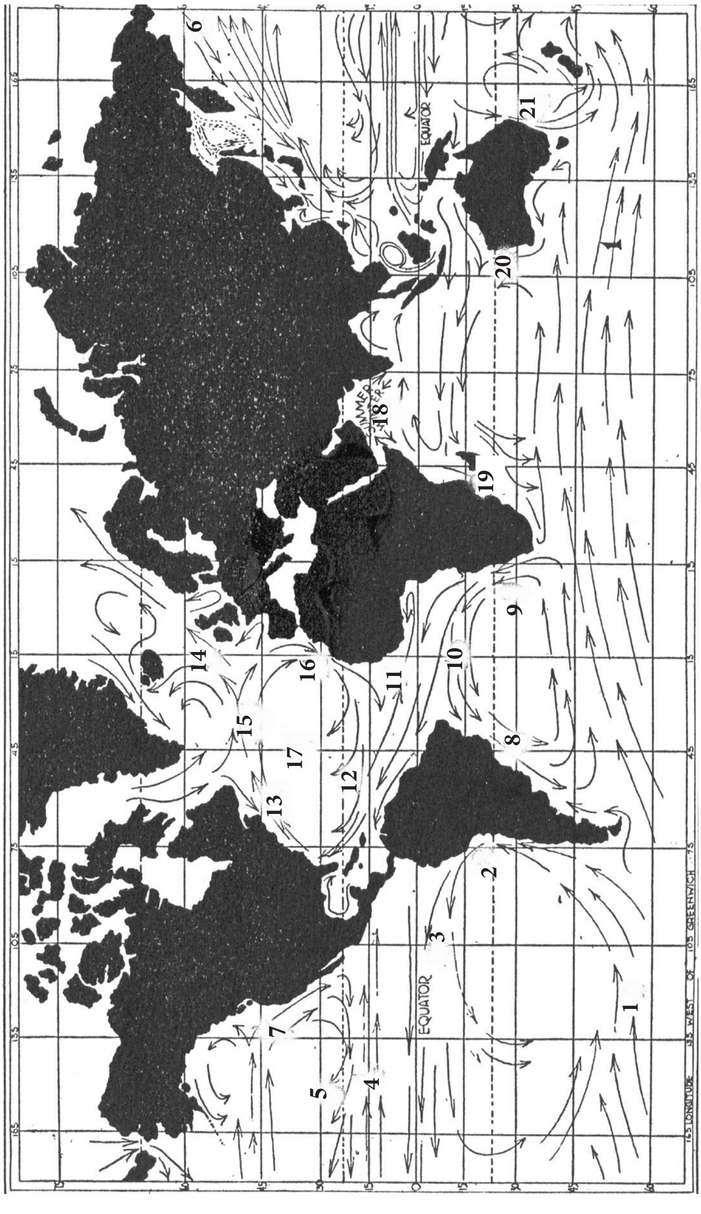
There are times when you cover distances faster than expected. Then there are times when progress seems to take forever. Furthermore, if the currents involved are not accounted for, there is a possibility of being carried off course on a dangerous heading.

Both the Planetary Wind System and the Coriolis Effect contribute to the predominant currents on the surface. We covered the Coriolis Effect in the previous chapter and, though the planetary winds will not be discussed until Chapter VIII, it will suffice here to say that the circulation on the surface of the ocean is substantially influenced by the prevailing winds which, in the temperate regions, are the so-called Westerlies that blow from the west, and, in the subtropics, are the Trade Winds blowing toward the Equator from the northeast in the Northern Hemisphere and from the southeast in the Southern Hemisphere.

At this point, it should be noted that, in describing a current, we indicate the direction in which it is flowing whereas we tend to name the winds on the basis of the direction they are coming from. Possible confusion is easily avoided simply by adding the words *from* and *toward*, when referring to winds. For example, in referring to the Northeast Trade Winds we can either describe them as blowing *from* the northeast or blowing *toward* the southwest.

Due to the mass of the water, currents have a momentum that keeps them moving at a relatively steady rate. Accordingly, the wind–driven flow moves onward in response to the prevailing winds, not to the ever-shifting winds that you may be experiencing. Also, current speeds are a great deal slower than wind velocities. For example, winds of 15 knots

Fig. 1. Ocean currents in February-March.



Ocean currents in February–March. (After Schott) 1. Antarctic West Wind Drift. 2. Peru Current (Humboldt). 3. South Equatorial Current. 4. Counter Equatorial Current. 5. North Equatorial Current. 6. Kuroshio Current. 7. California Current. 8. Brazil Current. 9. Benguela Current. 10. South Equatorial Current. 11. Guinea Current. 12. North Equatorial Current. 13. Gulf Stream. 14. Norwegian Current. 15. North Atlantic Current. 16. Canaries Drift. 17. Sargasso Sea. 18. Monsoon Drift (Summer East, Winter West). 19. Mozambique Current. 20. West Australian Current. 21. East Australian Current.

(17 mph) are regarded as little more than a strong breeze while current speeds are commonly less than 1 knot (<1 mph) and flows in excess of 3 knots (~3.5 mph), as may be experienced in the Straits of Florida, are considered unusually swift.

Let's take a global view of the surface currents experienced in traveling on the high seas. As we do so, bear in mind that we are generalizing. The variability is greater than appears on a world map such as shown on the previous page (Fig. 1). There are seasonal differences and, over continental shelf areas and near the coast, tidal currents and even the run-off from estuaries commonly prevail.

Let's begin with the circulation of the North Atlantic starting with the Gulf Stream System. A map of the Gulf Stream drawn by Ben Franklin and his cousin Timothy Folger, who was a whaling captain, was published in 1769 (Fig. 2). This sketch encouraged ship captains to take advantage of the favorable current when sailing to Europe and to take a route farther south when returning.

Fig. 2. The Gulf Stream as portrayed by Ben Franklin and Timothy Folger.

Later, Matthew Fontaine Maury, the pioneering oceanographer of the U.S. Navy (Fig. 3), elaborated as follows:

Fig. 3. Matthew Fontaine Maury, the pioneering oceanographer of the U.S. Navy.

> "There is a river in the ocean. In the severest droughts it never fails, and in the mightiest floods it never overflows. Its banks and its bottom are of cold water, while its current is of warm. The Gulf of Mexico is its fountain, and its mouth is in the Arctic Seas. It is the Gulf Stream. There is in this world no other such majestic flow of waters. Its current is more rapid than the Mississippi or the Amazon."

Maury set up a program calling for ship captains to report on their voyages in such a way that, as he analyzed the accumulated information, he learned about and described ocean currents worldwide.

The origin of the Gulf Stream System is the Florida Current which flows out of the Gulf of Mexico, around the Florida Keys, then north in the Straits between Florida and the Bahamas Banks. As the Gulf Stream proper it flows in more of an easterly direction; however, as meanders bud off both to the north and to the south, it becomes far more complex than the relatively narrow river described by Franklin, Folger, and Maury (Fig. 4). Though these meanders may pinch-off to form warm and cold core rings much of the flow eventually returns to the main direction of the Gulf Stream.

Farther to the east the Gulf Stream System flows on as the North Atlantic Drift. Much of this Drift is drawn toward the northeast partially replacing cold water that sinks to the depths in the Subarctic. In sinking

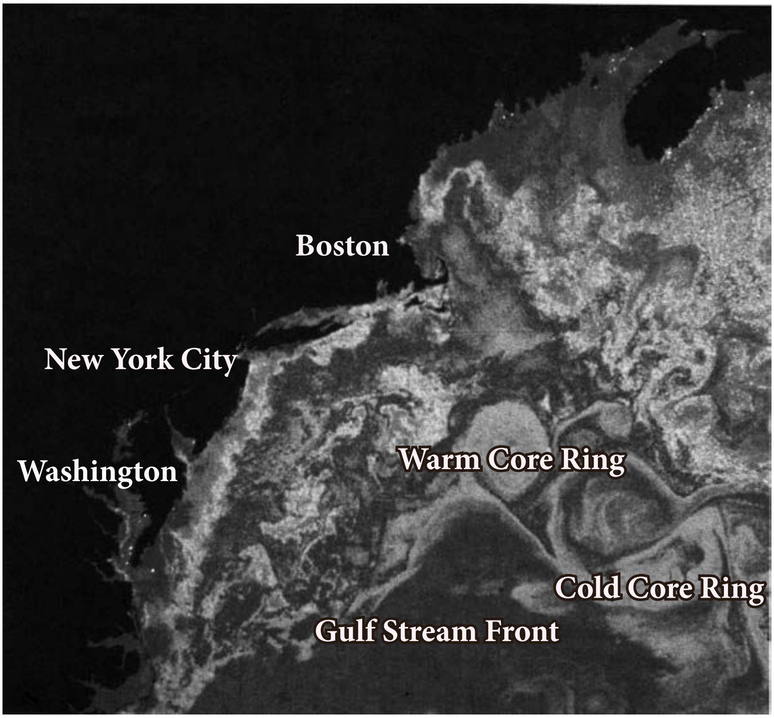


Fig. 4. The meandering Gulf Stream produces warm and cold core rings off the Mid-Atlantic coast. Source: NASA.

it forms the beginning of the deep water Conveyor Belt that drifts southward and, after a circuitous route in the depths, returns to the surface. The combination of the warmth from the North Atlantic Drift and the slow release of heat from the Westerlies results in relatively warm conditions in Northern Europe (Fig. 5).

In the eastern stretches of the Arctic there is also a Norwegian Current which moves relatively warm water into the Arctic Sea. The circulation in the Arctic generally rotates in a clockwise direction from the Beaufort Gyre which lies south and west of the North Pole and into which there has been considerable input from the Bering Straits between Siberia and Alaska. Much of the ongoing flow from the gyre is a transpolar drift ultimately toward Siberia and onward to the the northern tip of Greenland. From that general area there is some flow along the east and west coasts of Greenland toward the North Atlantic.

These current patterns in the water are subject to change whether due to the Arctic Oscillation, from global warming with decreasing ice cover and an increase of the effect of the winds, or from some combination of unfolding conditions. Since the currents in the Arctic tend to be very slow, in the order of 4 km (~2.5 miles) a day, they are of a little concern to the few who are travelling in the Arctic.

In crossing the North Atlantic, not all of the Drift of the Gulf Stream System moves to the north. Some of the drift flows on toward the West Coast of Europe, then takes a southerly course as the Canaries Drift.

The Mediterranean Sea lies off to the east of this southward drift. At the Straits of Gibraltor there is some surface flow into the Mediterranean which you may experience, and there is considerable outward flow below the surface into the Atlantic.

In effect, the Mediterranean is two seas; one is to the east augmented by interactions with the Adriatic and Aegean Seas and separated by the Straits of Sicily from the region to the west. Multiple factors result in such varied and transitory effects on the surface that I am at a loss to try to suggest what one might experience. Perhaps a little of everything that might be imagined, all depending on when and where you happen to be there. In my own defense, I might add that the full story of the circulation in these enclosed seas is yet to be unveiled. Due to the high rate of evaporation, you may notice that the water away from the coast tends to be quite salty.

Eventually, under the influence of the Northeast Trade Winds, there

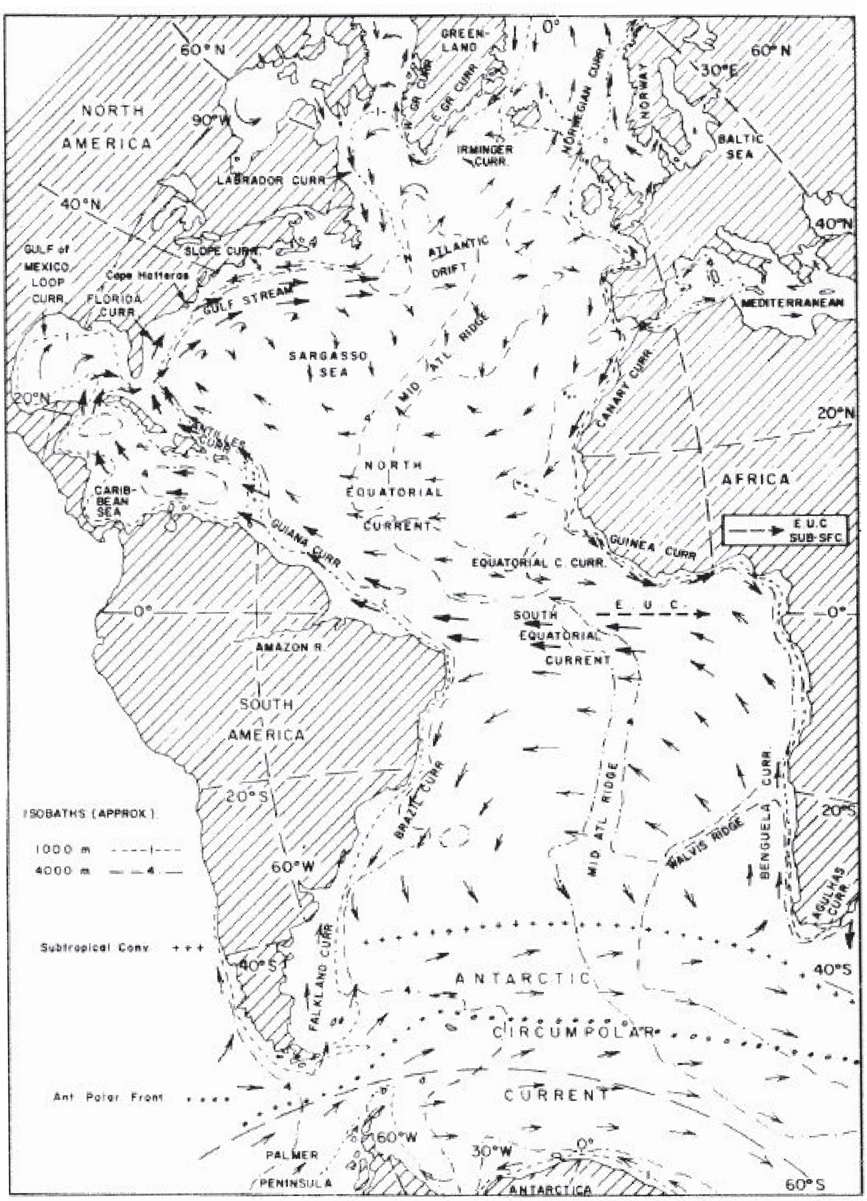


Fig. 5. Surface currents of the Atlantic Ocean. Source: Pickard, G. L. and W. J. Emery, 1990. Descriptive Physical Oceanography. *Pergamon Press, Oxford and New York, with permission from Elsevier.*

is a flow westward across the Atlantic as the North Equatorial Current. Some of this flow across the Atlantic returns to the Gulf Stream beyond the Bahamas Banks while some enters the Caribbean Sea where, joining with a current diverted from the Southern Hemisphere circulation, it flows on into the Caribbean Sea and eventually into the Gulf of Mexico. This completes the large gyre of the North Atlantic responding to a great extent to the prevailing winds, (i.e., the Westerlies and the Northeast Trade Winds). Also, the clockwise rotation involved conforms to the Coriolis Effect, (i.e., this overall circulation is to the right in the Northern Hemisphere).

You have probably realized, quite correctly, that along the western side of the gyre in the North Atlantic, in other words, in the Gulf Stream proper, the current is quite strong, deserving of the name "river in the ocean" as given by Maury. This western intensification, as it is called, is brought about by the clockwise rotation of the overall system.

Turning to the North Pacific, there is a similar western intensification known as the Kuroshio Current flowing in a northeasterly direction

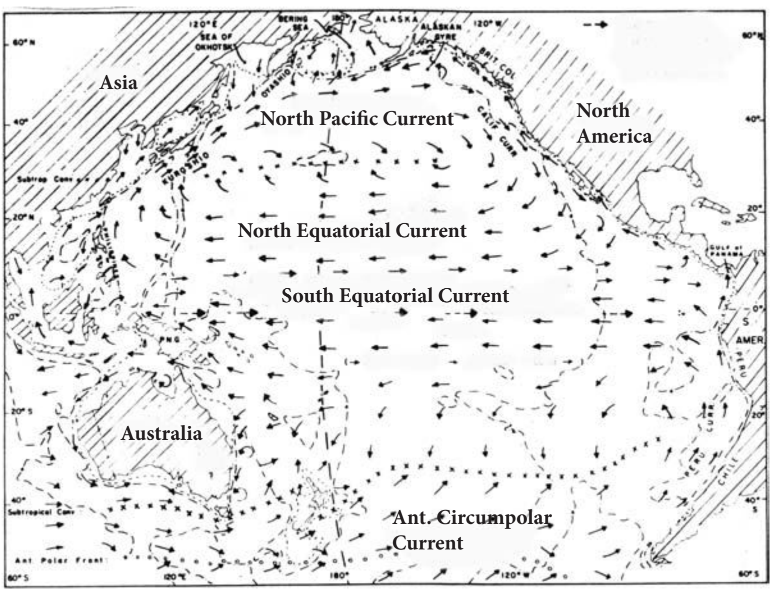


Fig. 6. Surface currents of the Pacific Ocean. Source: Pickard, G. L. and W. J. Emery, 1990. Descriptive Physical Oceanography. *Pergamon Press, Oxford and New York, with permission from Elsevier.*

past Japan. The ongoing flow across the Pacific is not as strong and, accordingly, is appropriately referred to as the North Pacific Drift (Fig. 6). A branch to the north forms the counterclockwise Alaska Current which returns, south of the Aleutian Islands, to the Drift across the Pacific. Ultimately, considerable flow from the west curves southward along the West Coast of Canada and the United States, becoming the California Current. This continues under the Northeast Trade Winds of the Pacific to become the North Equatorial Current thereby completing the gyre in the Northern Hemisphere of the Pacific.

In the South Atlantic, a combination of the Westerlies of the South Temperate region, the Southeast Trade Winds, and the Coriolis Effect opposite that to the north results in a giant counterclockwise gyre. While the flow along the West Coast of Africa is somewhat stronger, it is not comparable to the intensification associated with the Gulf Stream and the Kuroshio Current. As it flows westward some of it is deflected in a northwest direction, seemingly guided by the eastern bulge of the South American continent and leading into the southern and western Caribbean.

In the South Pacific, there is a counterclockwise gyre which includes the Peru or Humboldt Current off the West Coast of South America. As in the South Atlantic, this current is relatively strong though not comparable to the intensification associated with the circulation in the Northern Hemisphere. The current off the Northwest Coast of South America will be discussed further in referring to upwelling and to El Niño. (See the first addendum to this chapter, also Chapter IX dealing with upwelling and productivity.)

The pattern of gyres, as just described for the Atlantic and the Pacific, is also seen in the counterclockwise circulation of that part of the Indian Ocean that lies south of the Equator. However, in the mid– and northern reaches of the Indian Ocean, the currents are governed by monsoon winds which blow from the north off the Asian continent in the winter and from the south onto the continent in the summer. (These seasonal monsoons are discussed more fully, along with the weather, in Chapter VIII.)

In the Southern Ocean the main circulation system is the Antarctic Circumpolar Current flowing clockwise as driven by the Westerlies. There are areas close to the Antarctic continent where there is a counterclockwise flow propelled by Polar Easterlies.

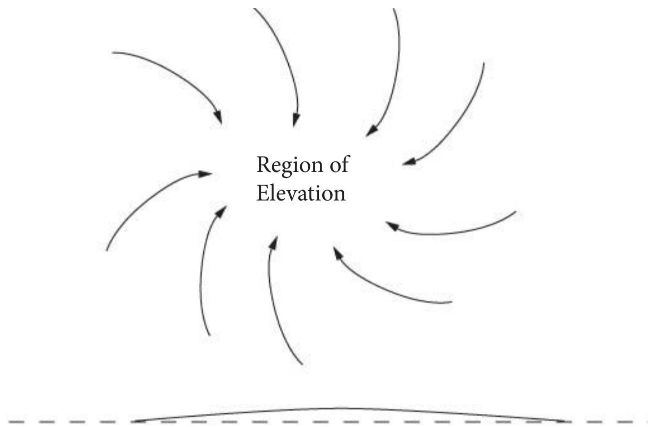


Fig. 7. Elevation of the surface of the sea in the middle of each of the major ocean gyres. Arrows indicate the Coriolis Effect. Above is a diagrammatic portrayal of the surface elevation; dashed line indicates level of surrounding sea.

In each of the great gyres of the Northern and Southern Hemispheres, there is a central elevation of the sea level of more than 1 m (3.28 ft) (Fig. 7). This is largely due to the Coriolis Effect with the flow turning toward the center in each hemisphere. Oceanographers, though certain that such elevations are real, had no means to measure them directly prior to recent sea level observations made by satellite.

Two accompanying figures that indicate that the general distribution of the temperature on the ocean surface tends to be what you would expect in view of the wind-driven circulation as just described (Fig. 8, 9). Of the many examples, I find it especially interesting to note that, as the Gulf Stream System moves on to the northeast, it brings warm temperatures and relatively mild conditions to the countries along the West Coast of Europe. I will never forget watching youngsters enjoying a good swim far to the north along the coast of Norway. To be sure it was summer but we were directly east of Labrador.

Another accompanying figure shows the average salinity patterns of the surface waters (Fig. 10). Without venturing deeply into the chemistry involved, it should suffice to say that the chemicals in sea water are derived largely from the erosion of the Earth's rocky crust plus inputs issuing from the interior of the Earth. The relative concentrations of these

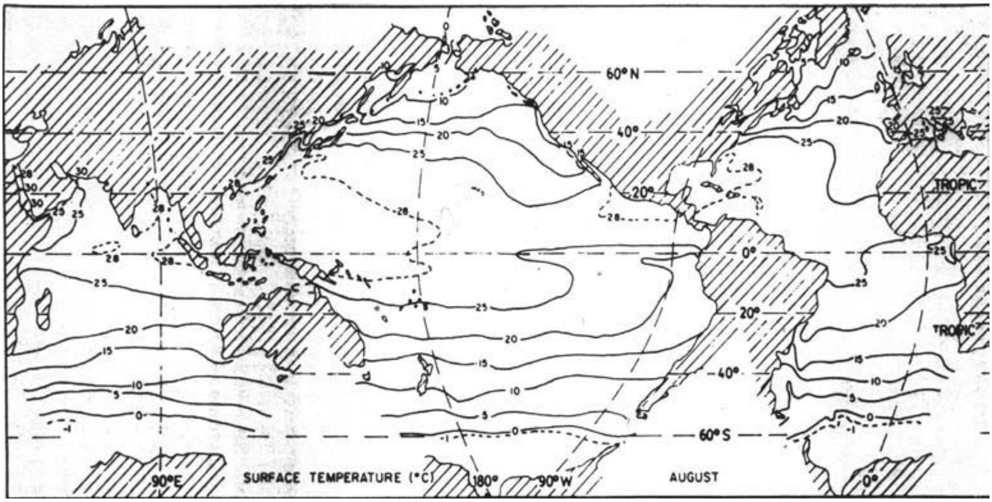


Fig. 8. Temperature in degrees C on the ocean surface during August. Source: Pickard, G. L. and W. J. Emery, 1990. Descriptive Physical Oceanography. *Pergamon Press, Oxford and New York with permission from Elsevier.*

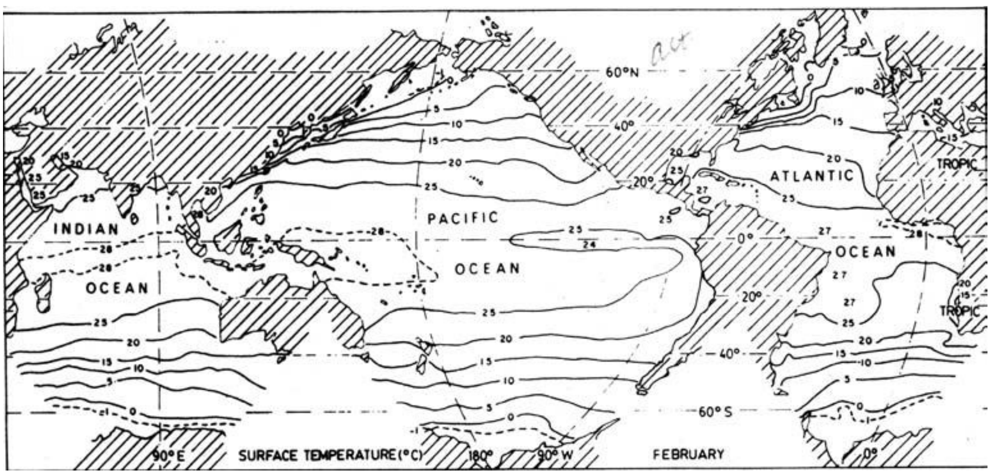


Fig. 9. Temperature in degrees C on the ocean surface during February. Source: Richard, G.C. and W.J. Emery 5th ed. 1990. Descriptive Physical Oceanography *Pergamon Press, Oxford and New York with permission from Elsevier.*

salts are as follows:

Salt	*Percent by weight*
Chloride	55.07
Sodium	30.62
Sulfate	7.72
Magnesium	3.68
Calcium	1.17
Potassium	1.10
Bicarbonate	0.40
Bromide	0.19
Strontium	0.02
Boron	0.01
Fluoride	0.01

In addition, a long list of constituents, including gold I might add, occur in trace amounts. In fact it seems likely that, with sufficient analyses, everything that occurs naturally, plus some artificially produced chemicals, are to be found in sea water. Judging from analyses made

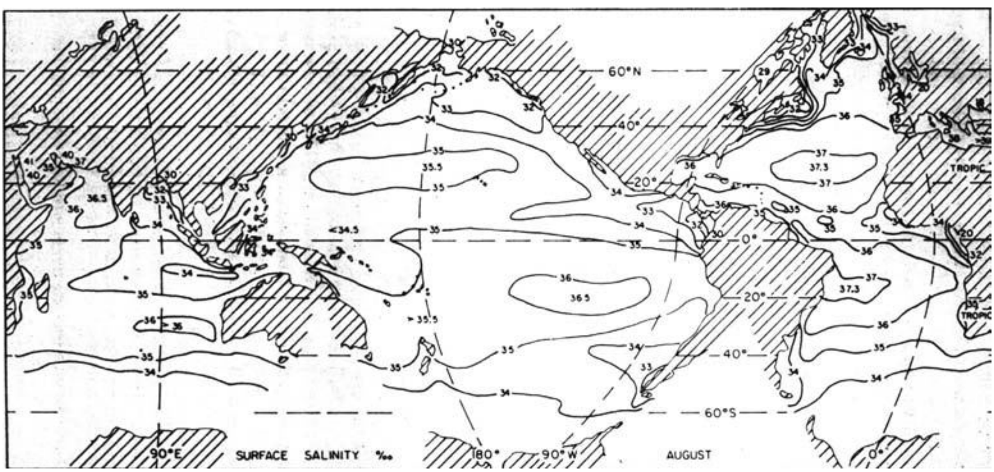


Fig. 10. Salinity in parts per thousand on the ocean surface. Source: Pickard, G. L. and W. J. Emery, 1990. Descriptive Physical Oceanography. *Pergamon Press, Oxford and New York, with permission from Elsevier.*

on old deposits, the relative abundance of the major salts in sea water has remained the same for at least the last 1.5 billion years. Some of the details regarding the salt regulation processes involved are yet to be determined.

The total salt in solution on the high seas does not vary greatly from an approximate mean of 35 grams for every 965 grams of water, which amounts to 3.5% and which oceanographers opt to express in parts per thousand (ppt) or 35 ‰. Using a titration technique or electrical conductivity sensors to obtain precise salinity data, physical oceanographers find that slight differences from the mean are very significant in understanding both the horizontal and the vertical circulation of the oceans. These differences involve the interplay of precipitation and evaporation at the sea surface. Accordingly, somewhat higher salinities are found in areas of high evaporation and low salinities are commonly found in cooler areas of high precipitation. Similarly, low salinities also occur in coastal locations affected by freshwater run-off from the land. Note that the salinity runs as high as 40 ‰ in the Red Sea which is a somewhat confined body of water in an arid, high-evaporation setting. While it doesn't show clearly in the accompanying illustration, it is well known that very low salinities occur well out to sea off the delta of the Amazon River. It is said that, as much as 50 miles away from the mouth, the water is fresh enough to drink.

Even without the technical means to determine salinity, you may be able to sense some of the extremes. For instance, by taste alone you can often detect that water off a river mouth is not as salty as that well offshore. If you are in a setting such as the Red Sea, the water may seem unusually salty to the taste buds. Should you be swimming, you may also sense that you are more buoyant where the salinity is high. (Changes in salinity relating to freezing and ice formation are discussed in Chapter VIII.)

As you followed the above descriptive accounts of the circulation on the surface of the ocean, with large volumes of water flowing in the directions indicated, you may have wondered what is involved in counteracting any tendency for water to pile up in distant areas. To a great extent vertical circulation is the answer; at the surface, the water moves down to the deep layers in some regions and upward toward the surface in others. Recall, for example, the sinking of cold water in the Subarctic of the North Atlantic that is the beginning of the conveyor belt flowing southward in the depths and subsequently returning to the surface. Also, in some cases we can readily account for a returning flow not at great depths but more directly on the surface. Thus, the East Greenland and the Labrador Currents return part of the large volume that has been carried northward by the North Atlantic Drift. As to the surface water that is transported toward the west by the Trade Winds, there are Equatorial Countercurrents with the one in the Pacific being greater than the Countercurrent in the Atlantic that merges with the flow from the Southern Hemisphere diverted into the Caribbean. Furthermore, as currents carry large volumes of water toward the Antarctic, cold water sinks far to the south and moves north at great depths. In essence, the overall circulation can be readily accounted for.

In considering the major circulation patterns, it is useful to couple these with what we know about the prevailing weather patterns and to account for some of the routes commonly selected for long distance voyaging. Starting again with the North Atlantic, it is obvious that for west-east travel in the summer, crossing well to the north is likely to be the best route as the Gulf Stream, the North Atlantic Drift, and the prevailing winds of the Westerlies are all favorable. Furthermore, being approximately along a Great Circle Route, this course comes close to being the shortest crossing one can make.

However, sailing from Europe to the Americas is quite another story, as skippers often take a more southerly route so as to benefit from the Northeast Trades and the accompanying favorable ocean circulation even though the distance is considerably greater. The routes selected for power-driven ships are more likely to follow a Great Circle whether traveling eastward or westward across the North Atlantic. They may shift a bit to the south when the threat of icebergs from the Labrador and Greenland Currents prevails.

You can also readily appreciate why sailors, in traveling across the Pacific, generally take what I have heard referred to as the "Coconut Run" involving first the Northeast Trades then, after crossing the Doldrums, the Southeast Trades. Except for the Doldrums, this route is generally very pleasant.

There are some very good guides for contemplating long distance voyages and they not only offer information on current systems but generalizations as to the weather as well. Some of these guides are listed at the end of this chapter. Also, Pilot Charts are available for many regions showing wind and

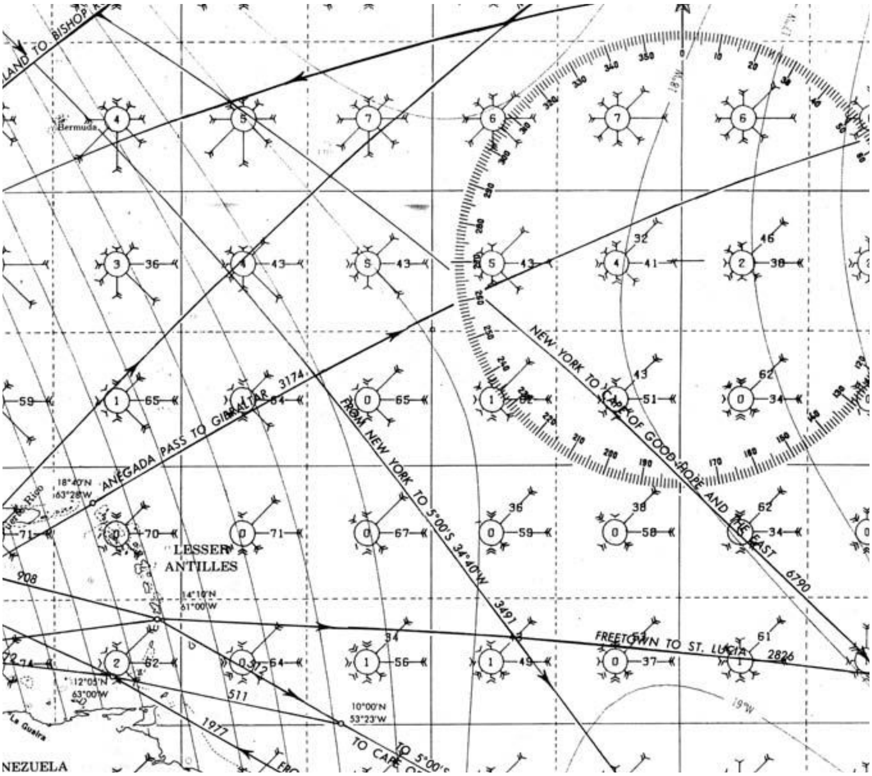


Fig. 11. A section of the Pilot Chart for July in the North Atlantic. Wind rose in each square shows the character of prevailing winds with arrows flying with the wind. The length of an arrow is in proportion to the percent of the time in which the wind is expected to blow from that direction. Where the length of an arrow will not fit within a square the line is broken and the percent is printed in the break. Number of feathers indicates the average force on the Beaufort Scale. Figures inside the circle are percentage of calms, light airs, and variable winds. (Note that, as most of the squares shown in this illustration are in the Northeast Tradewind belt, many of the prevailing winds are from the northeast and east.) Source: National Geospatial Intelligence Agency.

current conditions month by month in sections of about 5˚on a side (Fig. 11). Special features of The Pilot Charts include the information such as the percent of fogs and the southerly limit of icebergs. Various additional information of interest to those traveling the high seas may be found on the back of these charts.

To make this discussion more meaningful, I am suggesting a couple of exercises:

First, let's assume you are the navigator underway on an extended voyage. How did you select the route you are taking? How useful were large-scale maps of the currents and the winds, the Pilot Charts, and any published descriptions you found as to the best routes to take? How did the currents affect your progress? Have the winds and currents always been what you had expected? If not, can you explain the discrepancies?

Or, let's say you are involved in planning an extended voyage. Just what would you take into account regarding the currents and the winds? Of the sources mentioned herewith, which do you think would be most helpful?

Some guides to cruising the high seas:

World Cruising Routes by Jimmy Cornell. International Marine, Camden, Maine.

Admiralty Ocean Passages of the World by the British Admiralty. (This and the following guide are available from American Nautical Service, Ft. Lauderdale, Florida.)

Admiralty Sailing Directions (Pilots) by the British Admiralty.

Sailing Directions by the National Geospatial-Intelligence Agency of the United States.

Addendum

El Niño, Pacific Decadal Oscillation, and North Atlantic Oscillation

The rise and fall of pressure differences in the atmosphere may result in oscillations in the surface currents with accompanying changing conditions that you may be aware of. El Niño, the first to be discussed, has long been familiar to the general public.

El Niño Southern Oscillation (ENSO)

Ordinarily there is an upwelling of deep water off the coast of Peru and Ecuador as the Peru or Humboldt Current curves off to the west under the Southeast Trade Winds. This upwelling brings nutrients to the upper layers thereby greatly increasing the productivity and supporting the harvest of Anchovies, one of the largest fisheries of the world.

(See Chapter IX for a general discussion of upwelling in relation to productivity.)

The cumulative effect of changes in atmospheric pressure over the southern reaches of the Pacific may cause the Trade Winds to diminish and, as they weaken, a mass of warm water from the Western Pacific moves eastward across the ocean. When this happens, the upwelling off the coast of South America is shut down and widespread adverse conditions ensue. It is these conditions, based on changes in the southern atmosphere, that are referred to as El Niño Southern Oscillation or ENSO

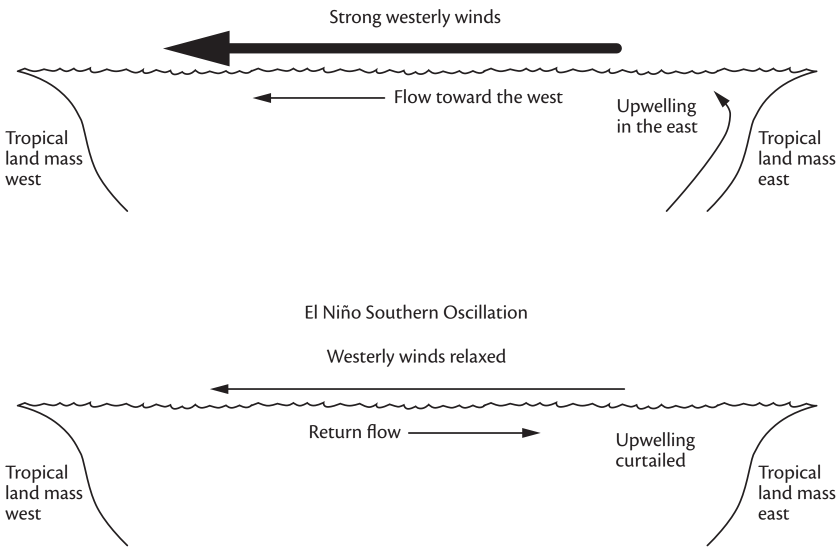


Fig. 12. Cross-section along the Equator in the Pacific. Top: During a normal year with strong trade winds. Bottom: During an El Niño event with trade winds weakened and sometimes reversed.

(Fig. 12). Referring to these phenomena as "El Niño" stems from the fact that they usually begin around Christmas and in spanish, the expression means "the Christ Child."

An immediate effect of the lack of upwelling is the temporary demise of the anchovy fishery. In turn the seabirds that rely on Anchovies as food become quite scarce and the thick layers of guano that the birds deposit on offshore islands and that are 'mined' for nitrate are not replenished.

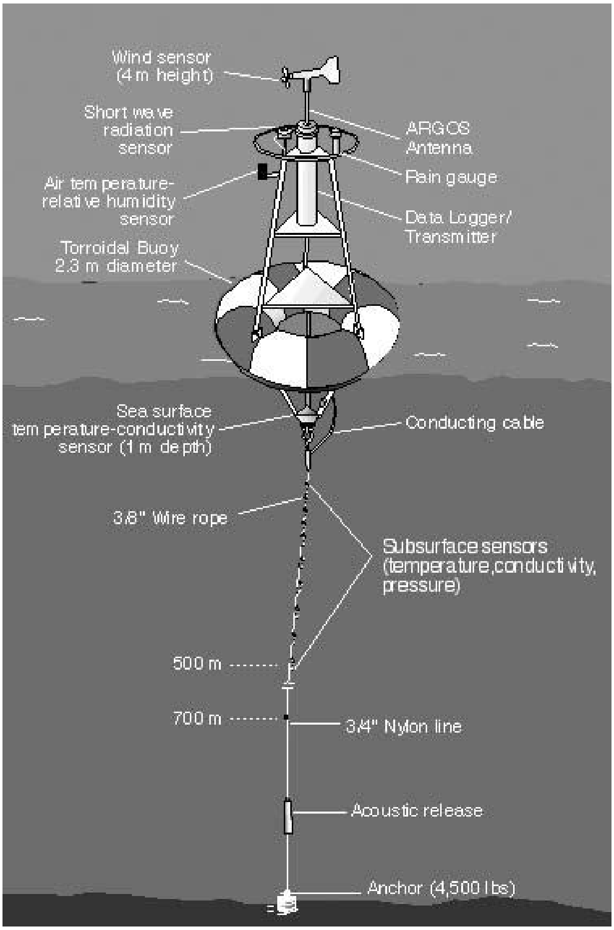


Fig. 13. Tropical Atmosphere Ocean (TAO) buoy. Source: NOAA.

Numerous other conditions develop, generally quite destructive, especially during a strong El Niño. Along the West Coasts of the Americas there may be very heavy rain with destructive winds, considerable erosion of the shoreline, and some adverse shifts in the coastal circulation. All this may be accompanied by drought conditions in the Western Pacific, becoming quite a problem in Australia and Indonesia. Further changes in the weather may be experienced around the globe.

While an El Niño may be short lived, not extending much beyond April, strong events such as the one in 1997–1998 can last about a year. Also, there may be as many as two large ENSO developments within a decade, but the occurrence of this phenomenon has been quite irregular.

After an El Niño, the former conditions of cold water off Peru sometimes moves in with more than the usual strength. This is referred to as La Niña.

Needless to say, meteorological and oceanographic research focusing on El Niño has greatly increased of late. The Tropical Ocean-Global Atmosphere Program (TOGA), international in scope, maintains an array of some 70 Tropical Atmosphere Ocean project (TAO) monitoring buoys stretched out in the Pacific along the Equator and a few degrees to the north and the south (Fig. 13). By satellite, the buoys relay information on the wind, current, and temperature on the surface and current and temperature to a depth of 500 ft. One of the obvious goals of this research is to develop the ability to predict the onset of an El Niño and, judging from recent reports, it now appears possible to do so within a one year lead time.

It should be noted here that there is an increasing use of buoys for extended oceanographic monitoring. There is a new worldwide network of some 3,000 drifting ocean sensors called the Argo system. These sink to the depth of about 1500 m, close to a mile, before returning to the surface and transmitting the recorded temperature. With the ocean comprising 70% of the Earth's surface, this extensive network should tell us a great deal concerning global warming.

North Pacific Oscillation, alias Pacific Decadal Oscillation (PDO)
Another well-known shift in the circulation of the ocean involves the flow across the North Pacific. This has tended to occur in cycles of some 20 to 30 years with either warmer or cooler waters reaching the coasts of North America. At the present time, cooler waters are reaching the Northwest Coast, resulting in high productivity and favoring the growth of salmon. To generalize, which is always risky, it seems that, in the warmer water years when salmon harvests are doing poorly off the West Coast, the reverse tends to be true in Alaskan waters when the PDO moves more to the north.

North Atlantic Oscillation (NAO)
Certain current modifications in the north Atlantic involve the air pressure differential between the Azores High and the Icelandic Low. A deepened Icelandic Low increases this pressure difference resulting in a

positive NAO index (NAO+). When the pressure differential is reduced, the index is negative (NAO-). Though the frequency and magnitude of these oscillation vary there was a long term trend spanning more than two decades with frequent lows from about 1960 until the 1980s.

Shifts in the index must have wide ranging impacts. Thus, when the index tends to be positive, there may be more frequent and stronger storms and the weather frontal systems may track farther north in the Westerlies wind belt. Also, the flow of the Gulf Stream System may track farther to the north bringing even warmer weather to Northeastern North America and northern Europe. Because of the short term variability in the pressure oscillations, effects on marine life have been difficult to determine but the likelihood of significant impacts is receiving a great deal of attention. For instance there is the possibility that the decline in the Atlantic Cod stocks may be due, at least in part, to environmental conditions brought about by the frequency of high indexes since the 1980s.

Oceanographers are paying increasing attention to the importance of changes in surface circulation resulting from oscillations in the overlying atmospheric pressure.

Addendum

Physical Properties of Water As Related to Oceanography: Some Highlights.[1]

Water is the only substance that in nature occurs in all three states: liquid, gas, and solid. To simplify the discussion which follows, I will be using the term *water* when referring to the liquid state, *vapor* when referring to the gaseous state, and *ice* when referring to the solid state.

One calorie of heat is required to raise the temperature of one gram of water 1˚C.[2] Accordingly, 100 calories are required to raise the temperature of one gram from the freezing to the boiling point, i.e. from 0˚ to 100˚C (Fig. 14). However, a change in state, as from water to vapor requires 540 calories per gram, and when a gram of water changes to ice, 80 calories are released. Correlated with these figures on a per gram basis is the release of 540 calories when vapor is condensed and 80 calories is required to melt ice.[3]

1 The properties referred to in this discussion are characteristic of freshwater. Differences associated with salinity are minor.

2 When applied with respect to foods the convention is to use the uppercase, namely Calorie, to indicate that 1,000 calories are involved. However, when it is obvious that food is being referred to, it is rather common to drop the uppercase designation.

3 The unique characteristic of water, wherein it expands just before freezing, is covered in Chapter VIII.

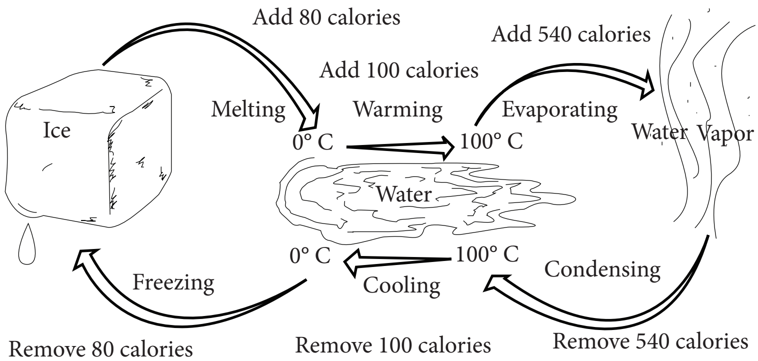


Fig. 14. Addition of heat: one calorie raises one gram of water 1˚C, 540 calories evaporates one gram of water, and 80 calories melts one gram of ice. Cooling: removal of calories in these same amounts results in lowered water temperature, condensation of vapor, and freezing.

Due to these heat exchange properties we find that water has a comparatively high heat capacity, actually greater than any other naturally occurring material on Earth. Thus a great deal less heat, generally energy from the Sun, is required to warm the land than to do the same for the water nearby. The well-known sea breeze during the day, discussed in Chapter VIII illustrates this as the land gets warm during the day and the overlying air rises giving way to an onshore breeze of more dense air from over the comparatively cool adjacent sea. This also applies to the seasonal monsoons of southeast Asia also discussed in Chapter VIII.

There are many heat exchange effects that you may be aware of as an observer. For instance you are probably aware that a coastal maritime climate tends to be more moderate than the range of conditions experienced far from the sea. More of an everyday experience is the cooling effect when sweat evaporates.

Another important property of water is its role as a solvent. More substances—solids, liquids, and gases—dissolve in water than in any other common liquid. Accordingly, water is often referred to as the *universal solvent*.

The high degree of transparency of water is important as it allows for the penetration of the Sun's energy as light which supports life through photosynthesis. (See Chapter IX). There are many additional ways in which transparency enhances activity in aquatic environments.

This is not an exhaustive review of the properties of water. Some others will come to mind in relation to topics discussed in succeeding chapters.

Chapter VII.
Tides and Tidal Currents

I was told of someone digging clams in Penobscot Bay, Maine, when the Moon was full and the tidal flats were relatively bare. How could this be when we all know that it is largely the "pull" of the Moon that causes the tide to rise? Such apparent contradictions can and do occur, so you must consider some very complex interactions if you are to understand the tides as you experience them.

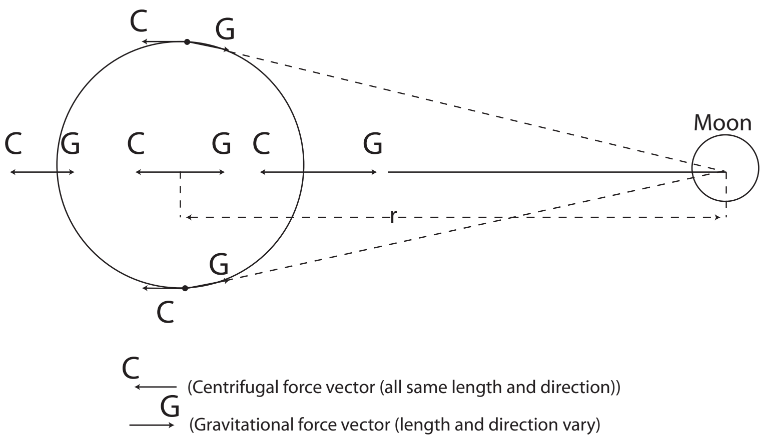


Fig. 1. The gravitation and centrifugal forces responsible for the tides, shown with the Moon located over the Equator. Source: Weiss, H.. M. and M. W. Dorsey, 1979. Investigating the Marine Environment. *Project Oceanology, Groton, CT.*

I suggest that we start with an oversimplification; then add interacting effects until the real, very complicated, tidal regimes are accounted for.

An extreme simplification is to think in terms of the Earth as a planet without continents and covered with a continuous layer of water of uniform depth.

With the Moon on the plane of the Equator in Fig. 1, let's compare two rather different effects: (a) with the Earth facing the Moon; and (b) with the Earth facing in the opposite direction. In (a) gravity causes the sea level to rise. In (b) gravity is still in effect though slightly reduced because of the greater distance from the Moon and in this case, the direction results in a lower sea level. The centrifugal effect due to the Earth's rotation on its axis deducts from the sea level rises on side (a) while in (b) with the effect being less restrained by gravity there is a net rise in sea level which tends to approximate the opposite rise on side (a). The overall result is the existence of two highs and the intervening lows passing any given point on the Earths' surface in the course of each lunar day of 24 hours and 50 minutes which is the elapsed time for one rotation of the Earth coupled with one circuit of the Moon around the Earth.

To continue we must add the role of the Sun which has a mass far greater than that of the Moon but is much farther away. As gravity decreases with the square of the distance, the tidal influence of the Sun is only about 46% that of the Moon.

Inasmuch as the lunar day lags 50 minutes behind the rotation of the Earth, there is a continuing change in the combined effects of the Moon and the Sun. The second sketch shows that, when the relative positions of these two bodies are on the same or opposite sides of the Earth, as is the case at the time of the new and full Moons, we experience the highest and lowest tides. These are referred to as 'spring tides.'[1] The so-called 'neap,' or tides of minimum range, occur when the Moon is in its first or third quarter (Fig. 2).

As we continue to consider the interactions of the Moon and the Sun, it is important to note that the declination of the Moon in relation to the plane of the Equator moves from north to south and back every lunar month and ranges as much as 28.5° north and south, while the declination of the Sun ranges from 23.5° north to 23.5° south and back every year (Fig. 3). This means, of course, that the comparison of

1 With respect to tides, the word "spring" does not refer to the season of the year.

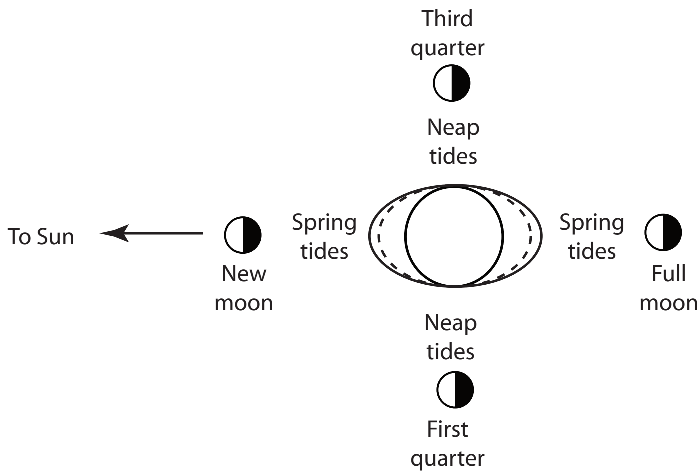


Fig. 2. Interacting gravity effects involving the Moon and the Sun and resulting in spring and neap tides. Source: Weiss, H. M. and M. W. Dorsey, 1979. Investigating the Marine Environment. *Project Oceanology, Groton, CT.*

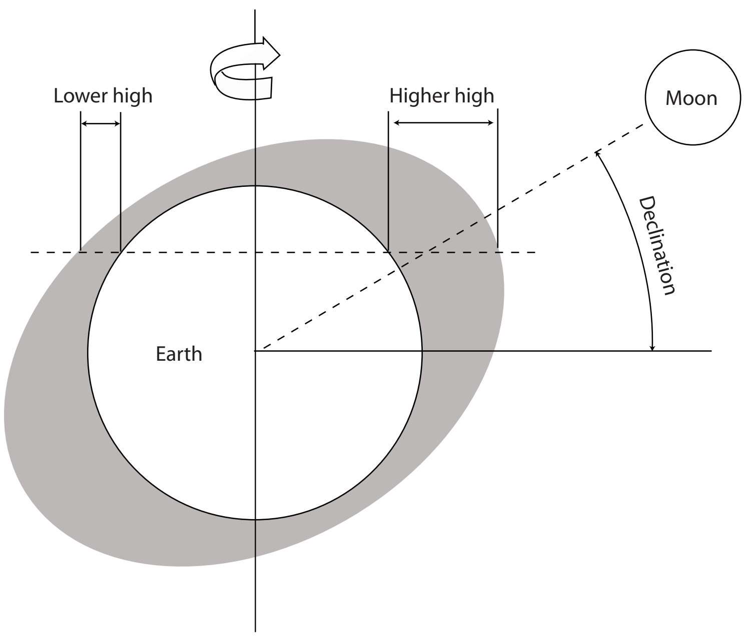


Fig. 3. Diurnal inequality of tidal wave height due to the declination of the Moon. Source: Williams, Jerome, John J. Higginson, and John D. Rorbaugh. 1968. Sea and Air: the Naval Environment. *United States Naval Institute, Annapolis, MD.*

declinations of these two bodies changes from time to time. Also, the changes are further complicated by the fact that the Sun and the Moon are very seldom on the same plane with respect to the Earth. (In view of this, you can understand why an eclipse is such a rarity.)

Though tidal regimes will never be exactly semi-diurnal unless the Moon and the Sun are both directly over the Equator, we usually consider them as such when the declination effect as quite small. Under greater declinations we get mixed tides (i.e. with a high-high, and lower high and a lower and lesser low (Fig. 4)).

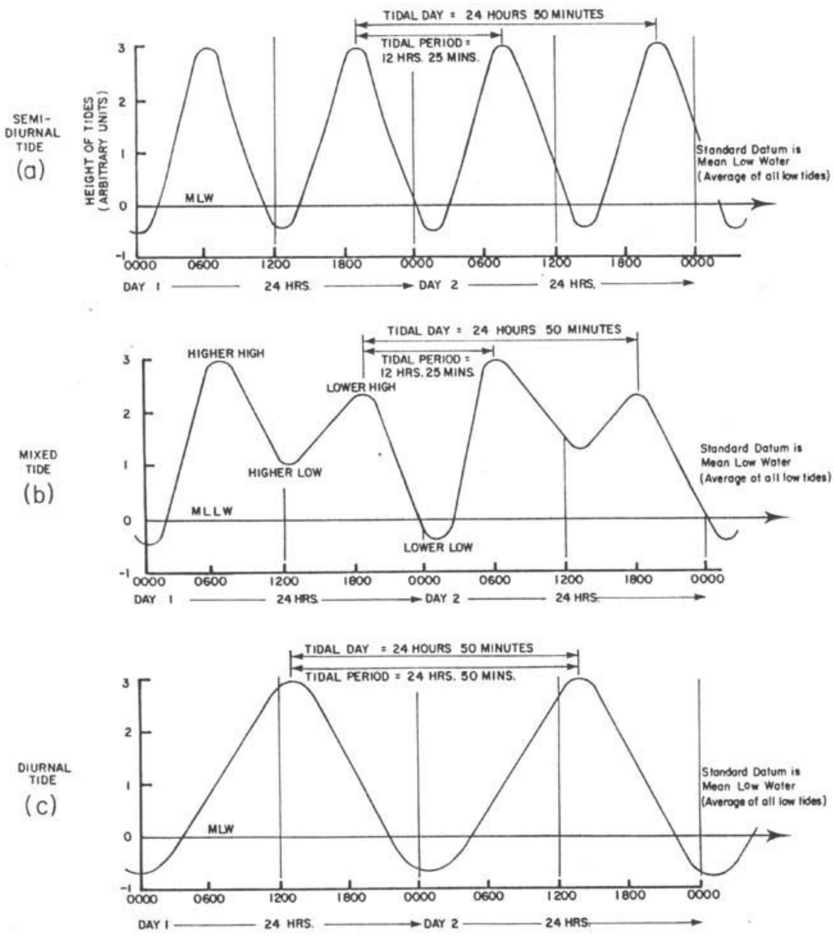


Fig. 4. Semidiurnal, mixed, and diurnal tide plots. Source: Weiss, H. M. and M. W. Dorsey, 1979. Investigating the Marine Environment. *Project Oceanology, Groton, CT.*

On the high seas there are two elliptical sea surface currents every 24-plus hours relating to the tides. Where diurnal, the ellipses are about equal. Under mixed tidal influences, separate ellipses develop. Since the rate of these rotations is commonly about 10 cm/second (0.02 knots) is seldom more than 30 cm/second and the accompanying flow rotates back and forth, the net effect is negligible on the wind-driven circulation.

The limited and greatly oversimplified account of the tidal phenomenon as presented thus far is commonly referred to as the Equilibrium Theory which helps to describe the basic role of gravity. However, we must turn to a more realistic approach, commonly referred to as the Dynamic Theory, which takes into account the mass of the water, the existence of the continents, the bathemetry of the ocean basins, the Coriolis Effect, friction, and the many additional effects that further influence the direction, speed, volume, range, and periods of the tidal waves. The objective is to fully explain the tides as we actually experience them.

As to the progression of the tidal wave across the ocean surface, it is only in the Southern Ocean near Antarctica that, though dragging somewhat behind, the tidal waves move directly in response to the combined pull of the Moon and the Sun. Elsewhere the waves turn to the north into the basins bordered by the continental land masses. In several of the ocean basin areas, the tide waves oscillate as modified standing waves reflected off one continent and back to the continent on the opposite side. With their direction modified by the Coriolis Effect, these oscillations may become giant spirals as shown in the accompanying illustration of cotidal lines which indicate the progression of wave crests over the surface of the ocean. These are usually drawn at hourly intervals (Fig. 5). Where such cotidal lines converge there are points where there is no crest, in other words no tidal range. These are referred to as amphidromic points and are analogous to the nodes of no motion of simple standing waves. In the past it was necessary to rely to a great extent on theory when drawing cotidal lines. Now that we can directly determine the elevation of the sea surface by satellite, our contours of cotidal lines are very reliable. It is interesting to compare old contours,(i. e., those derived theoretically), with new ones determined by satellite, for they match quite well.

At the ocean boundaries; however, in the comparatively shallow waters over the continental shelf and along the coast, the tidal flow is much

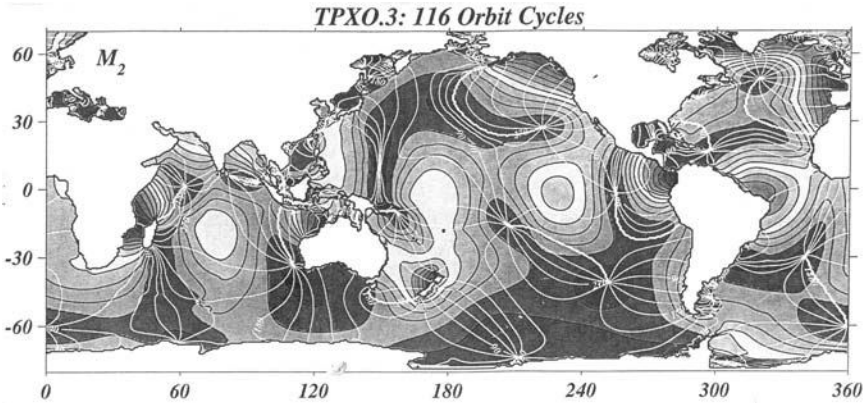


Fig. 5. Cotidal lines as determined by satellite. Also shown are amphidromic points where these lines converge. Source: From discussion with G. D. Egbert.

greater, resulting in the familiar, and often strong, flood and ebb tidal currents with slack water when the tide changes. The direction, strength, and timing of these coastal tidal currents and the highs and lows along the shore that accompany them are governed by the volume of the tidal waves involved, the bottom typography, the features of the coastline, the Coriolis Effect and numerous influences along the coast and in the estuaries.

Information as to the range of these tides is readily obtained from tide gauges but obtaining information as to the flow of the currents is quite a challenge. Actually, the information compiled in the familiar current charts of coastal and inshore areas involves extensive current observations (Fig. 6, 7).

Because of differences in the bathymetry and overall coastal dimensions, each coastal area responds differently to forces that govern the tides. Accordingly, while the tides are close to being almost semi-diurnal for many regions, there are areas with mixed and even with diurnal tides. The Gulf of Mexico, for example, with a natural oscillation period of about 24 hours responds more to the daily tidal constituents of the tide generating forces and tends to have a diurnal tide along much of the coastline (Fig. 4, 8). Finally, the orbit of the Moon around the Earth and the circuit of the Earth around the Sun are both slightly elliptical. Since the Earth is closest to the Sun in the Northern Hemisphere winter,

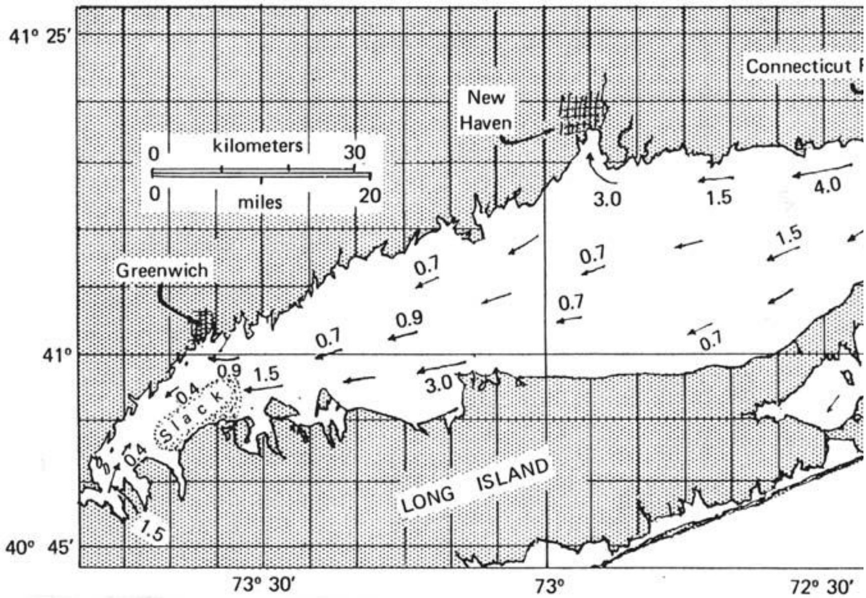


Fig. 6. Currents during a flood tide in Long Island Sound. Numbers indicate current speed in km/hour. Source: U.S. Coast and Geodetic Survey.

the Sun has its greatest effect on the tides during that time of the year.

As you become familiar with the tidal current and the range of the tide in various areas, you may also notice that the range is not correlated with the current velocity. For example, in the Gulf of Maine the range of the tide is quite large almost everywhere, yet the opening of the Gulf to the adjacent ocean area is so great that the currents involved are not particularly strong. On the other hand, in Nantucket Sound the range of the tide is only two or three feet yet the currents running through this restricted bathymetry can be quite swift.

When the flooding and ebbing "swing" of the tide is enhanced by the natural oscillation characteristic of a given region, the resonance involved can result in unusually highs and lows with accompanying faster currents. The front of such currents is called a tidal bore. A famous example is the Bay of Fundy with a natural period of about 12 hours and spring tides funneling into the embayment range more than 15 m (50 ft) (Fig. 9, 10).

Tidal bores are by no means uncommon. The bore near the mouth of the Amazon River, known as the Pororoca, is more than 7.5 m

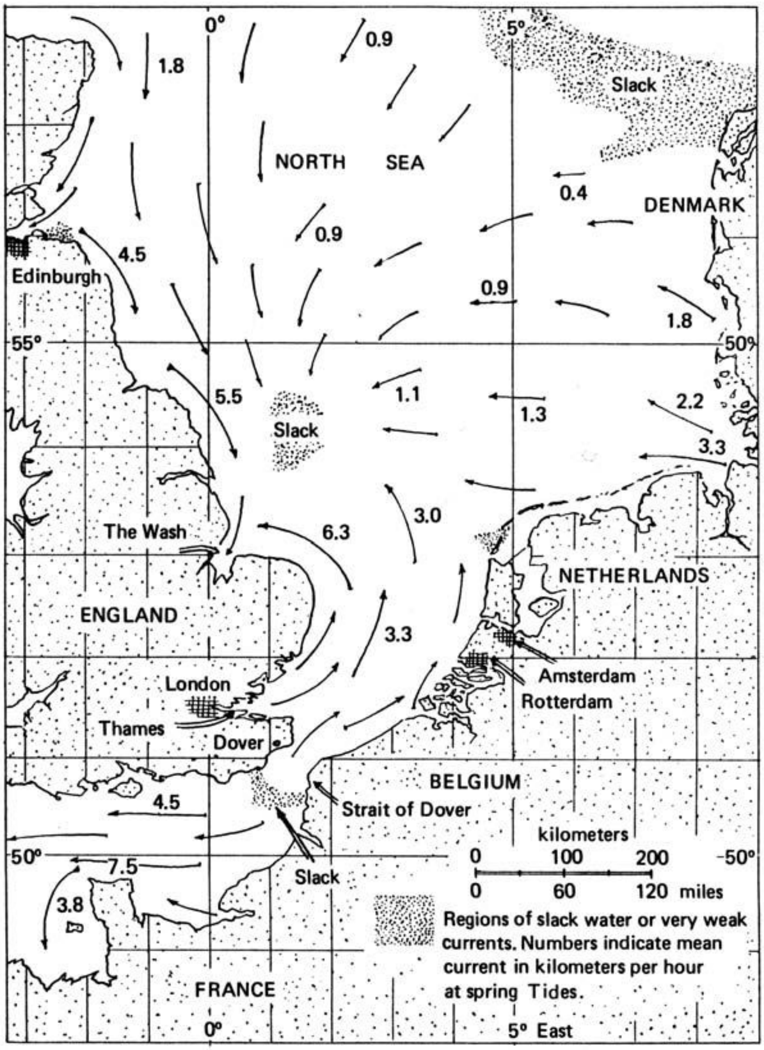


Fig. 7. Tidal currents in the North Sea during spring tides. Numbers indicate current speed in km/hour. Source: U.S. Naval Oceanographic Office.

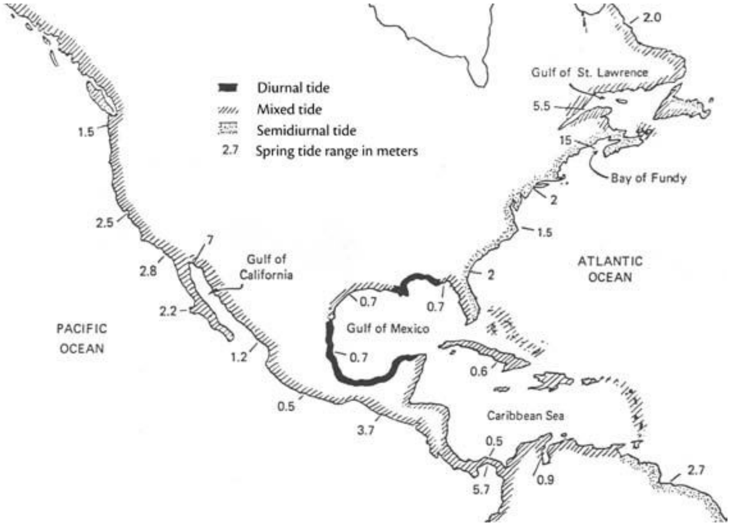


Fig. 8. Spring tidal ranges in meters around North American coastlines. Source: Oceanographic Atlas of the North Atlantic Ocean, *Sect. 1. Tides and Currents, Publication 700. Washington, D.C.*

(25 ft) high and 16 km (10 miles) wide. In height it is matched by the bore in the Qiantang River in China. There is a bore at the head of the Gulf of California; in France a bore is seen on the flats surrounding Mont Saint-Michel and another on the Seine. In Alaska, there is a bore on the arm of Cook's Inlet. A listing of sites worthy of mention could go on and on. Note that many of these are experienced well up into the estuaries involved.

Although the tidal regimes inshore may differ a great deal, the high and low tides and the currents along the coasts and in the estuaries reoccur in such a way that they are very predictable. Tide gauge records, readily obtained, serve very well for predicting the range of the tides. A full year of observations may suffice, though data for several years may be needed for inshore areas subject to varying impacts such as floods. Obtaining data on tidal currents is much more difficult. Direct and extensive current observations throughout the inshore areas are required and it is necessary to 'iron out' considerable noise due to winds, estuarine discharge, etc.

Finally, for all predictions of the tides it is necessary to take into account the relative positions of the Moon, the Sun, and the Earth which change over a period of 18.6 years; therefore, analyses and predictions must span this prolonged period of time.

As an afterthought relating to the last two chapters, I find it interesting to generalize regarding the relative importance of the prevailing winds and the gravity–based tidal currents on the high seas and near the coast. As noted, the tidal currents are so limited on the high seas that they have almost no effect on the circulation generated by the winds. On the other hand, in coastal areas the tidal currents are sufficiently strong that they generally prevail over the wind-driven circulation.

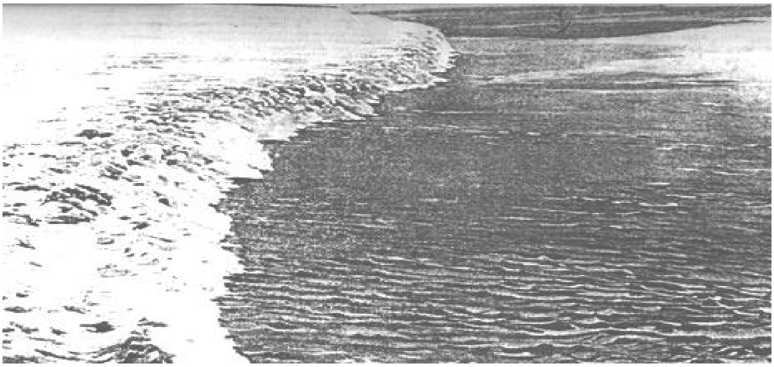


Fig. 9. Tidal bore at the head of the Bay of Fundy. Source: London News 1910 by anonymous photographer.

Fig. 10. Ladder fishing at low tide in the Bay of Fundy. Source: Canadian Information Service.

Chapter VIII.
A Little Meterology

✦

Undoubtedly, the weather is your uppermost concern when on the high seas. You never know just what might develop. Even in the relatively steady Trade Winds you might have to deal with a norther or the threat of a hurricane (alias tropical cyclone or typhoon).

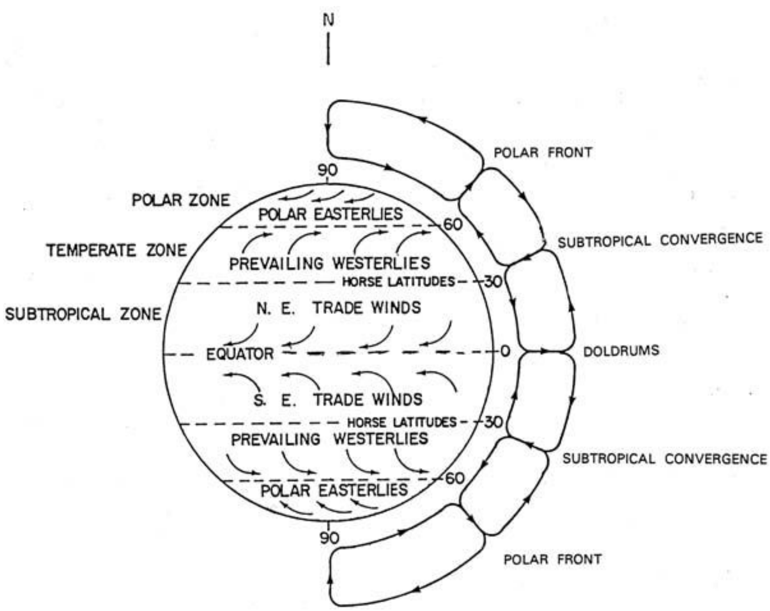


Fig. 1. The planetary wind systems.

From the Equatorial to the polar regions, three large wind zones prevail: the Tradewinds, the Westerlies and the Polar Easterlies. Separated by the Doldrums, the Subtropical High Pressure or Convergence, and the Polar Front, the pattern has the off-hand appearance of three large convection cells with air rising, moving toward the Poles, and descending back to the surface as it cools. One can describe the planetary winds in terms of three zones to the north and south as shown on the accompanying portrayal (Fig. 1).

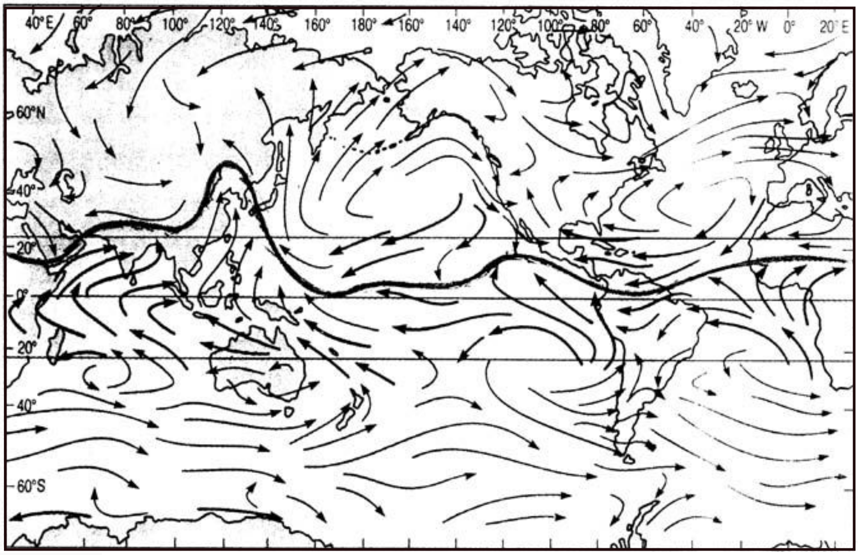
Starting with the descending Subtropical Convergence at approximately 30° to the north and to the south and shifting somewhat with the seasons, there are the Northeast and Southeast Trade Winds blowing toward the Equator. You can usually count on the winds to be rather steady in the Trades, commonly blowing around 10 to 15 knots (~12-18 mph) and seldom a great deal stronger. The conditions at sea may be almost perfect, particularly if you are under sail, are traveling from east to west, and there are no hurricanes in the offing. If you have a need for freshwater, the rain squalls are most welcome.

In the Equatorial region conditions are not as favorable. As the air becomes warmer there is considerable evaporation. Then, as the warm air rises, expands, and cools, the vapor condenses. It is a region of prolonged calms and heavy rains. These are the Doldrums: hot, muggy, with little or no wind, and generally just plain frustrating for those under sail. One's only consolation is the prospect, as in the Trades, of collecting rainwater and taking a shower.

Since the continental land masses are predominantly in the Northern Hemisphere and solar heating over the land is greater than over the ocean, the so-called Meteorological Equator and the accompanying Doldrums tend to lie slightly north of the true Equator; more so in summer than in winter (Fig. 2).

In the Subtropical Convergence, mentioned above in locating the Trades, you may experience extended calms but, as these are regions where the air is descending, the atmosphere is quite dry. In the North Atlantic this convergence has been dubbed the Horse Latitude, for it is said that, as sailing ships were becalmed, any horses being transported were thrown overboard because of their heavy demand on the limited freshwater supply.

The Westerlies, extending from the Subtropical Convergence to about 60° either north or south, are characterized by ever-changing weather



mean position of Intertropical Convergence Zone (ITCZ)

prevailing wind direction (≥ 50 % of observations)

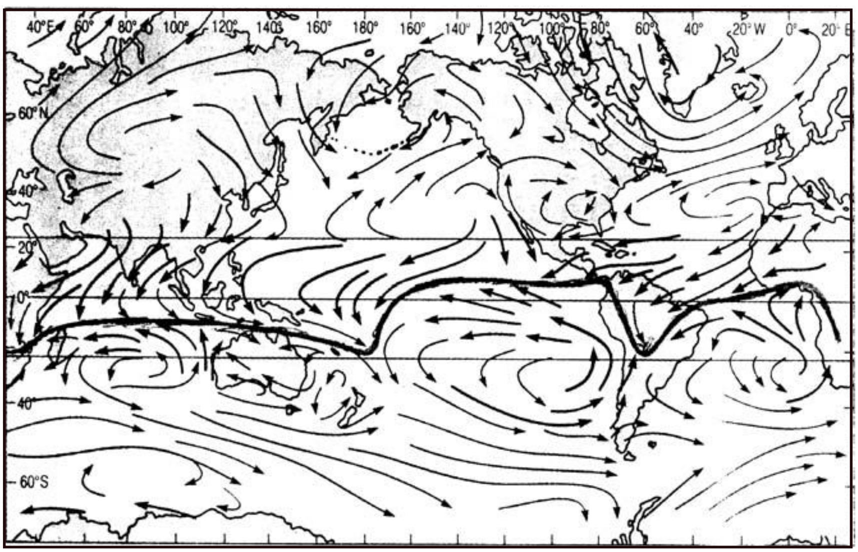


Fig. 2. Prevailing winds. The solid line shows the shifting position of the Intertropical Convergence Zone (Doldrums area). Upper figure represents Northern Hemisphere summer; lower figure represents Southern Hemisphere summer. Source: Open University, Author and Publisher.

involving air masses of different origins and fronts where the air masses overlap, extratropical cyclones, differing areas of high and low pressure, the winds of the jet streams, and much more.

Though there is considerable variation in the characteristics of the fronts, we will generalize and portray them as a succession of warm and cold fronts progressing from west to east across the Westerlies wind belt (Fig. 3). A warm front may develop where a warm air mass overtakes one that is somewhat colder, with the difference in temperature and humidity generally depending on where each one originated. Warm fronts are not noted for unusually high winds but the variable conditions typically include prolonged wet weather.

In a cold front, the cold air is pushing against the warm. Here too, of course, the condition of the air masses involved depends on where each originated. Cold fronts may be stormy regions with high winds, and sometimes violent thunderstorms (Fig. 4). Rapidly dropping barometer readings may warn of an approaching cold front and, in the extreme, the winds may increase to hurricane strength, 120 km/h (or 74 mph). Particularly important are the cold polar fronts as they move into the Westerlies and overtake warmer air mass conditions. Unlike the extended duration of a warm front, the conditions of a cold front tend to move in rather rapidly and pass on rather quickly, followed by a rising barometer and cooler clear air.

In the common sequence where a cold front overtakes a warm front, an occluded front is formed with an apex that is the focus of an extratropical cyclone formation. Subject to the Coriolis Effect, the extratropical cyclones that develop from the fronts rotate counterclockwise in the Northern Hemisphere and clockwise in the the Southern (4, 5, 6).

In the Northern Hemisphere high pressure from the polar regions will sometimes force colder weather to intrude well to the south. This may take the form of the familiar northers such as encountered blowing into the Gulf of Mexico and the Caribbean.

In the Southern Hemisphere there are regions south of the continental land masses, where there is more of an uninterrupted flow of winds from the west averaging 15 to 25 knots (17 to 29 mph). As they often get considerably stronger to the south, we have what sailors may refer to as the roaring forties, furious fifties, and screaming sixties.

Global high and low pressure areas and the jet streams affect the course of such unfolding weather developments (Fig. 7, 8). Noteworthy

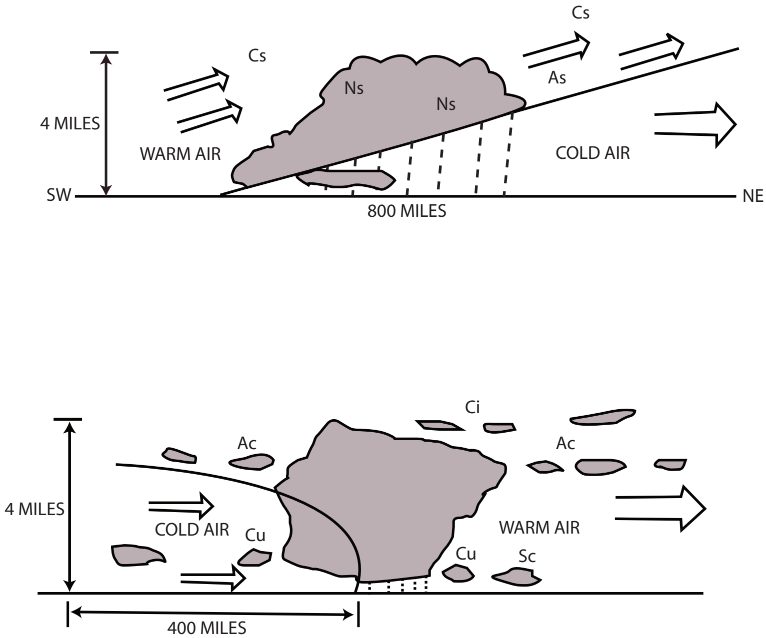


Fig. 3. Warm and cold fronts. Letters suggesting the cloud types likely to be present are: Ac: altocumulus; As: altostratus; Ci: cirrus; Cs: cirrostratus; Cu: cumulus; Ns: nimbostratus; Sc: stratocumulus. Source: Williams, Jerome, John J. Higginson & John D. Rohrbough. 1986. Sea and Air: The Naval Environment. United States Naval Institute, Annapolis, MD.

are the highs over oceanic areas, also low pressure areas in the winter in the North Atlantic and the North Pacific appropriately referred to as the Icelandic, and the Aleutian Lows respectively. Pressure over the continents in the mid and high latitudes tends to be low in the summer and high in the winter.

Jet streams are strong winds blowing from west to east often at 10,000 to 12,000 m (35,000 to 40,000 ft). The predominant jet stream in the Northern Hemisphere follows an undulating course along the higher latitudes of the Westerlies. The winds can be very strong. In fact they may flow as high as 260 knots (300 mph), though this is exceptional.

With the fronts, the extratropical cyclones, plus cyclonic rotations associated with high pressure areas, and various other conditions not

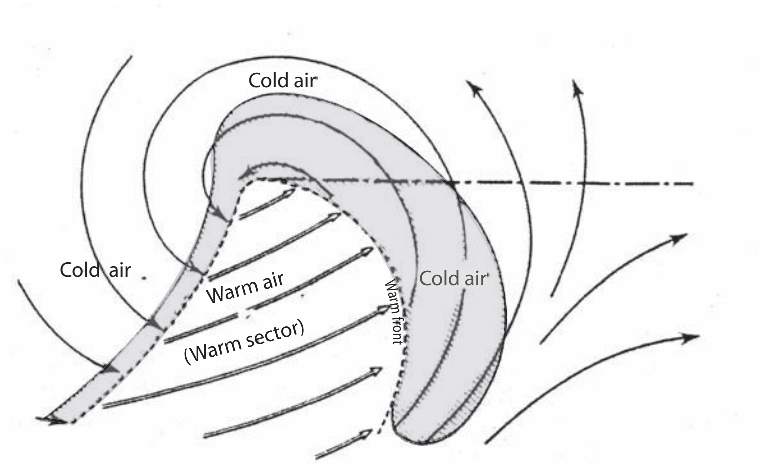


Fig 4. Frontogenesis showing the progression of warm and cold fronts. Shaded area indicates precipitation. Source: Bjerknes' cyclone model.

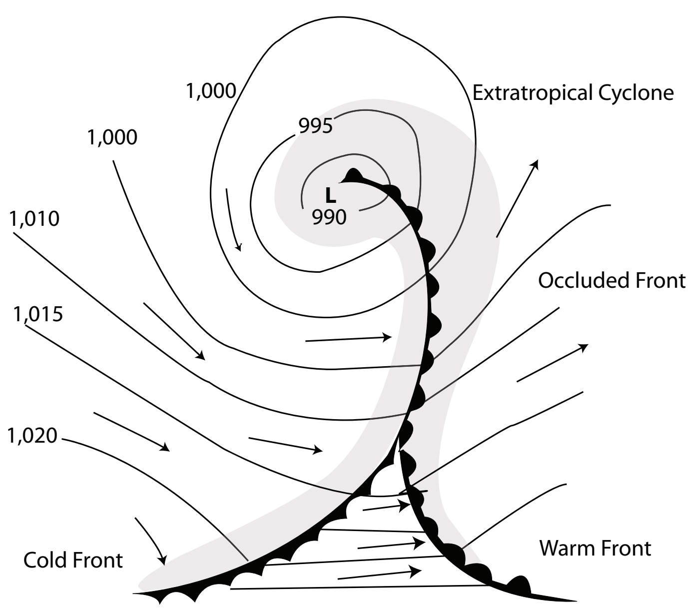


Fig. 5. Cold front has advanced over warm front to form an occluded front and the low pressure center of an extratropical cyclone. Common Weather Bureau Illustration.

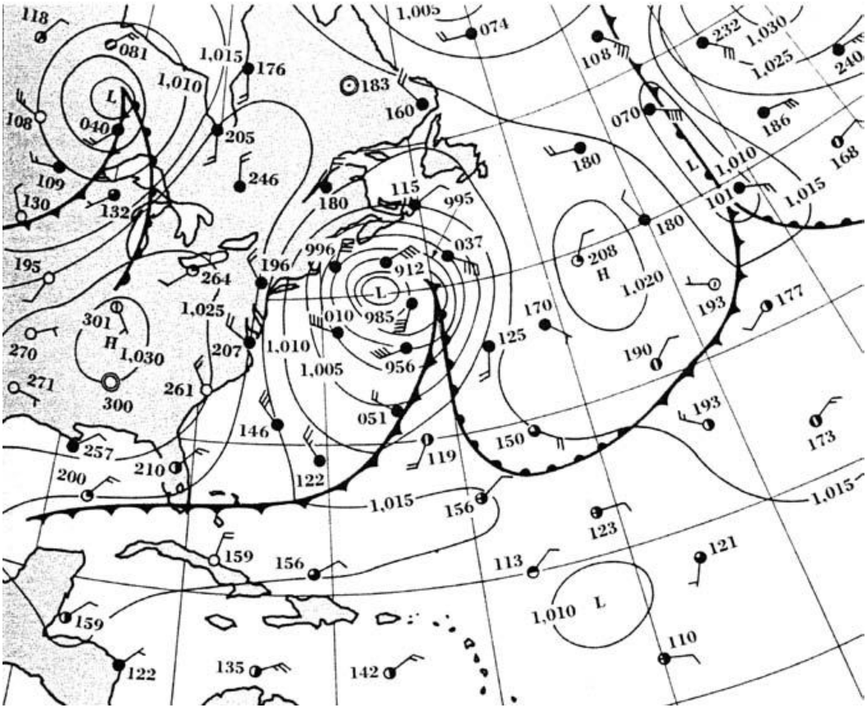
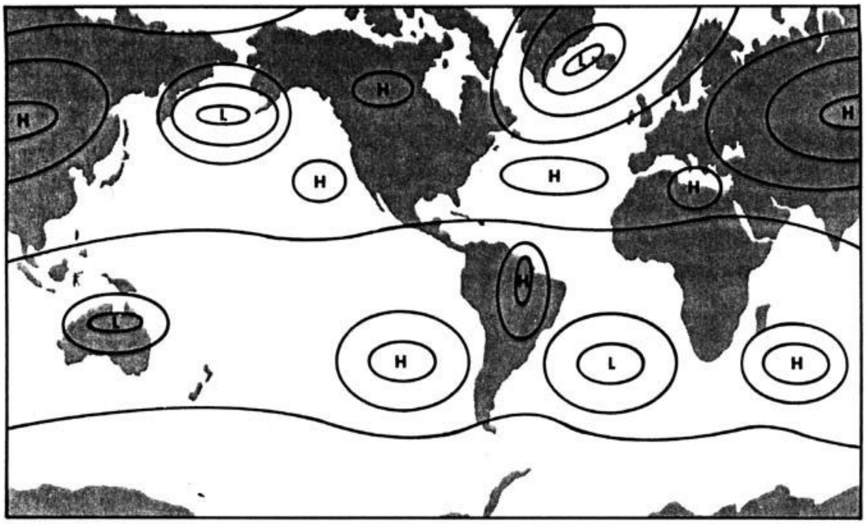
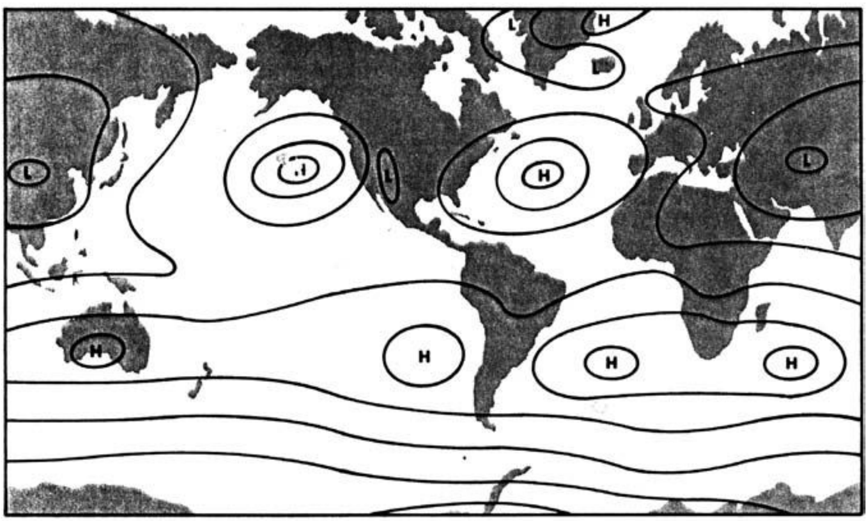


Fig. 6.Weather chart over the western North Atlantic showing well developed extratropical cyclone. Note the high winds near the low pressure center. Source: U.S. Weather Bureau.



Mean Pressure Pattern (January)



Mean Pressure Pattern (July)

Fig. 7. Atmospheric pressure areas. Source: Williams, Jerome, John J. Higginson & John D. Rohrbough. 1986. Sea and Air: The Naval Environment. *United States Naval Institute, Annapolis, MD.*

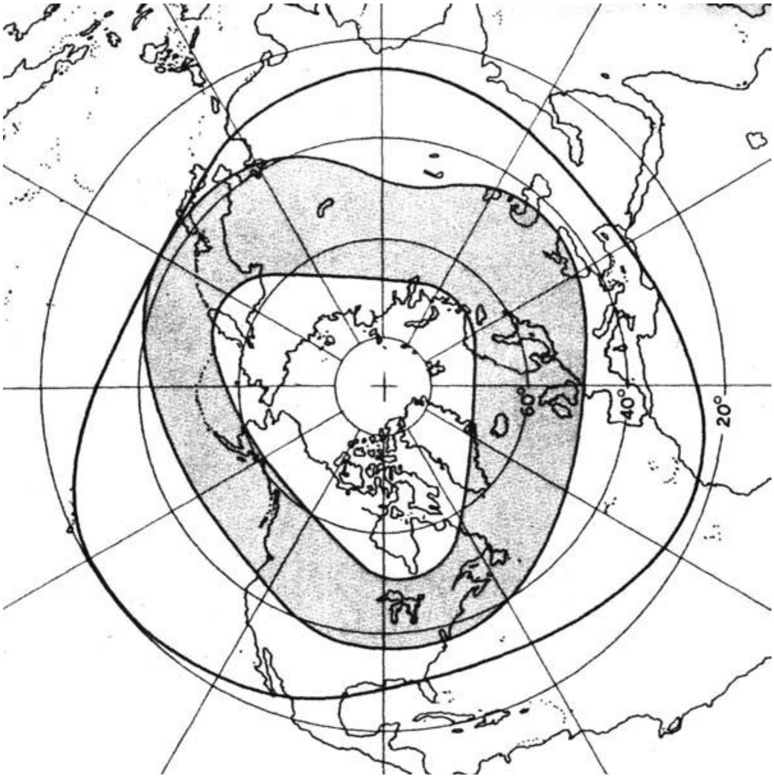


Fig. 8. Winter activity of the major polar front jet stream wanders over the shaded area. The single line is the mean winter position of the subtropical jet stream. Source: Technical Report 32, Department of Atmospheric Sciences, Colorado State University.

covered in this condensed discussion, the complicated weather patterns of the Westerlies wind belt generally, as noted above, progress around the planet from west to east. At sea much of your concern involves the fronts and extratropical cyclones which, though they often move through as moderate weather conditions, may bring on stormy weather. As noted, cold fronts tend to arrive more rapidly and with greater force than warm fronts. And, except for cyclonic weather originating in the tropics with the extreme being the hurricanes, dangerous stormy weather in the Westerlies is most likely to occur in the higher latitudes and during the winter months.

Since a falling barometer often indicates the approach of adverse weather, keeping up with barometer readings is very useful. A rapid drop in pressure suggests that you are on a collision course with stormy weather or, as is not unlikely, you are already experiencing inclement weather. A combination of increasing stormy weather and a low barometer may suggest that a change of course is advisable. In this case, it helps to know the appropriate location of the low pressure condition you wish to avoid. If you are in the Northern Hemisphere the actual center of low pressure is 90˚ to 120˚ off to the right as you face into the wind and, if the low pressure is passing to the north the wind may be inclined to veer around as the low pressure passes.

In the Arctic and Antarctic regions the Polar Easterlies are important, with weather conditions about as complicated as those of the Westerlies. Much of the precipitation is likely to be in the form of snowfall and even blizzards, and the cold tends to be accentuated by reflection of cold air off the snow and ice.

The following table should serve as a useful summary of the weather described thus far:

Weather descriptions by region

Approximate region	Name	Surface winds	Weather
0˚ or slightly N	Doldrums	Light & variable	Cloudy, variable rain in all seasons
0˚-30˚ N & S	Trade Winds	From northeast in the Northern Hemisphere, from the southeast in the Southern Hemisphere	Considerable rain though generally quite clear; occasional hurricanes
30˚ N & S	Subtropical High	Light & variable	Little cloudiness; dry in all seasons
30˚-60˚ N & S	Westerlies	Varied, sometimes quite strong	Air masses, fronts, extratropical cyclones
60˚ N & S	Polar Fronts	Variable	Stormy, cloudy weather, ample precipitation in all seasons
60˚-90˚ N & S	Polar Easterlies	From the northeast in the Northern Hemisphere, southeast in the Southern Hemisphere	Cold polar air with very low temperatures

To further cover the large scale weather systems we must turn to tropical cyclones that originate in the Tradewind zone and are better known to many of us as hurricanes, or as typhoons to those in the Western Pacific and willy-willies in the Australian region (Fig. 9, 10, 11, 12). Also we must consider seasonal monsoons which dominate over much of the Indian Ocean.

The formation of such a tropical cyclone begins as winds flow toward an area of warm moist air rising from the ocean surface in the tropics. What follows becomes a truly thermodynamic engine with winds increasing in strength as they blow toward the center where the air is rising, expanding, and cooling. The cooler temperature then causes the vapor, accumulated from the warm sea surface waters, to turn to heavy rainfall and release heat. Where the sea surface is sufficiently warm so that there is ample moisture in the air, the heat released helps to sustain the high winds.

In the Northern Hemisphere, the Coriolis Effect causes the spiral flow of the winds to rotate counterclockwise around the center. This rotation is clockwise in the Southern Hemisphere. (The direction of rotation is the same as described above for extratropical cyclones.) Tropical cyclones generally progress in a westerly direction out of the subtropics and eventually curve toward and into the Westerlies. The winds are strongest where their direction coincides with the direction in which the cyclonic system is moving. If possible, navigators seek the other side of the system.

Category 5, the strongest hurricanes, may have winds as high as 300 km/hr (about 180 mph), and fully developed systems can be more than 500 km (~300 mi) in diameter. Once hurricanes encounter conditions in which the moisture input is not as great, as is the case over dry land or where the seas are cooler, they begin to lose strength.

Such systems generally only develop in regions of sufficiently warm water. Also, they are not likely to develop close to the Equator since the Coriolis Effect needed to initiate the cyclonic rotation is not sufficiently strong.

In the North Atlantic and the Eastern North Pacific there is a distinct hurricane season starting in June and running to early November. Where tropical cyclones occur in the Southern Hemisphere, the season runs from late December through April or, as you would expect, roughly the reverse of the season in the north. In other areas where there are tropical cyclones they may occur in most any month, though in the western

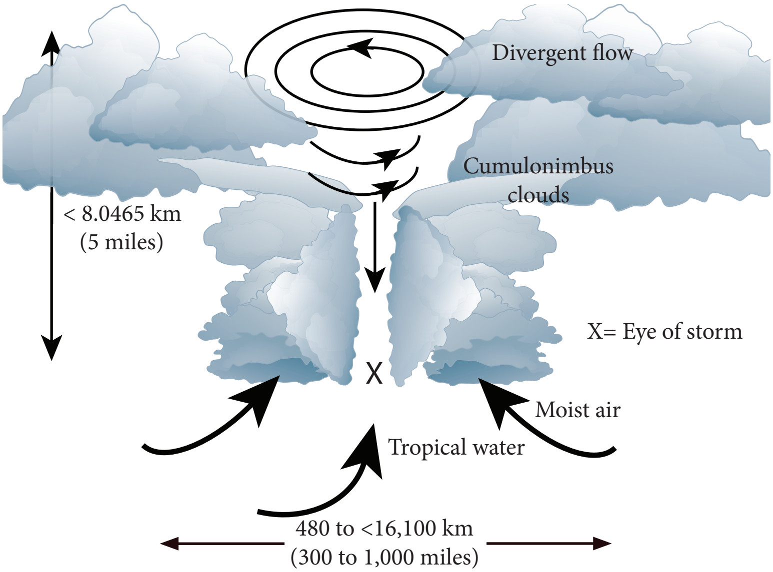


Fig. 9. Schematic diagram of a hurricane showing rising, spiraling columns of strong winds with heavy precipitation from cumulonimbus clouds, the whole system being driven by moist winds over tropical waters. In the center of the system there is a downward core or eye, and high above there is a broad divergent flow of warm, moist air.

region of the North Pacific they are a bit more frequent in July through October.

A few added thoughts come to mind. The changing direction of the wind in these rotating systems often results in some very confused seas. Also, as tropical storms are typically traveling across the open ocean, the large fetch may produce unusually high seas. When such waves happen to come ashore at the time of high tide, the surge can be very disastrous. And finally, if you experience the core or "eye" of such a storm with its unique calm and clear weather, remind yourself that more stormy conditions will follow close behind.

In the *American Practical Navigator* (originally by Bowditch), available in most any nautical bookstore, there is a discussion of indicators one can use to anticipate the track of a developing hurricane. For those who may be venturing into a region where such storms occur, this lengthy discourse is well worth studying. Keep in mind, however, that these weather systems may stall and may change in direction, speed, and wind velocity. Thus it is important to keep up with the best available weather advisories and, as mentioned later in this chapter, these days such information by radio is quite good.

On a much smaller scale, water spouts may be seen whirling and rising off the surface of the sea (Fig. 13). Some water spouts are essentially tornadoes wandering from off the land. The more common type is a simple convectional feature of the atmosphere that may occur almost any time in temperate or tropical latitudes and may be associated with fair weather or foul. As they arise almost spontaneously, they are difficult to predict but most are not nearly as dangerous as tornadoes.

As the updraft spirals of these spouts are very narrow, one can usually steer clear. Only recently, however, I watched a TV show in which a sailing yacht was overtaken by a water spout. The crew saw it coming, lowered all sails, and battened down. It seems that when the spout was rather close, the boat was sucked toward the center. It was rough going but they survived. Either they did not have auxiliary power enabling them

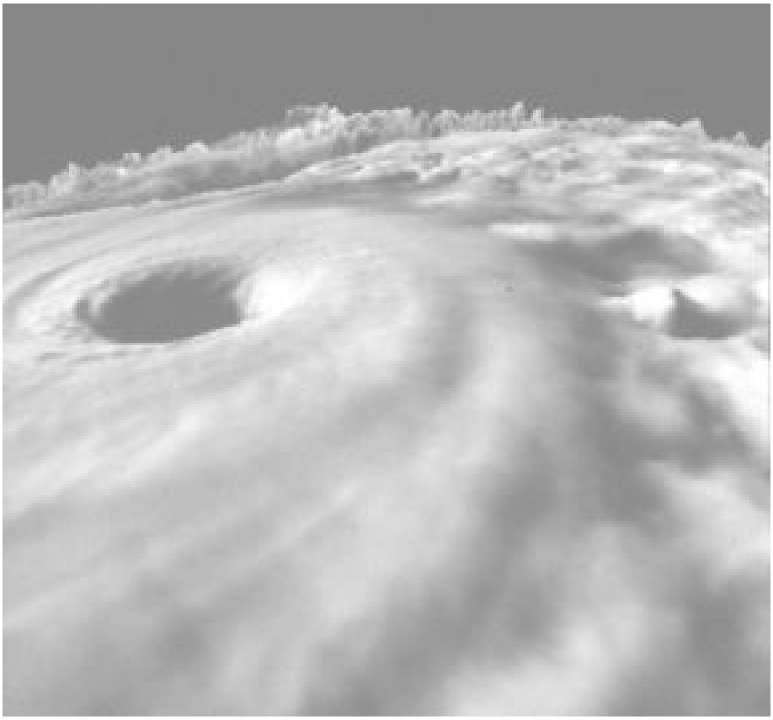


Fig. 10. Satellite view of the upper surface of Hurricane Diana photographed on Sept. 11, 1984. Source: NOAA.

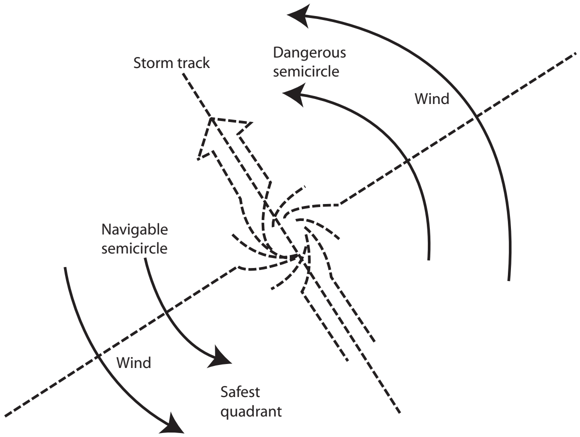


Fig. 11. Surface winds of a hurricane indicating the more dangerous regions where the progression of the storm adds to the strength of the wind as contrasted with the quadrants where the progression decreases the wind strength. Source: Williams, Jerome, John J. Higginson & John D. Rorbaugh. 1986. Sea and Air: The Naval Environment. *United States Naval Institute, Annapolis, MD.*

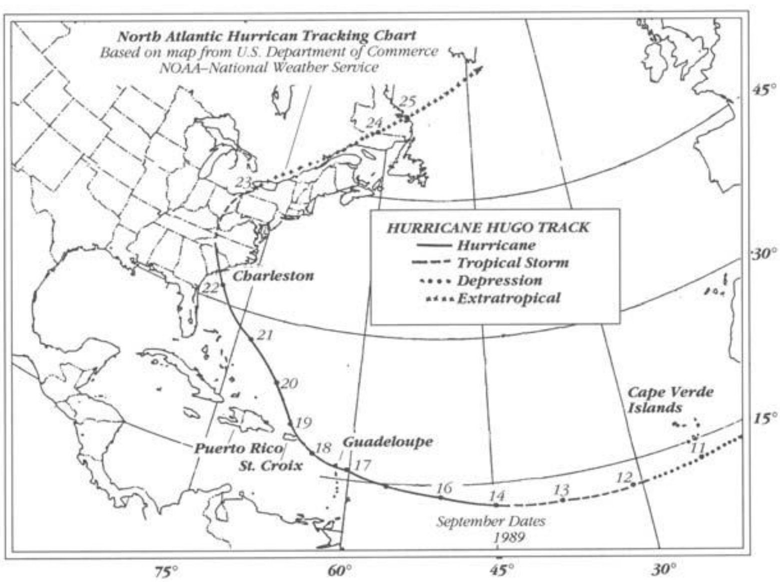


Fig. 12. Track of Hurricane Hugo. Making landfall at about 220 km/h (140 mph) in 1989, Hugo is typical of strong hurricanes approaching the southeast coast of the United States. Source: NOAA.

Fig. 13. Waterspout observed in 1969 from an aircraft off the Florida Keys. Source: NOAA.

to avoid danger or, since they were racing, they figured they could "tough it out" without using the motor and thereby becoming disqualified.

Off southern Asia a seasonal pattern of monsoon winds prevails as pressure differences develop between the continent and the neighboring seas. In winter, when the air over the continent becomes more dense, the winds blow south across the Indian Ocean and the South China Sea. In the warm weather, when the air over the continent gets warmer and tends to rise causing the pressure to drop, the seasonal monsoon winds blow in a northerly direction. These seasonal winds extend as far as the Southeast Trade Winds and prevail over the Westerlies, the Northeast Trades, and the Doldrums that characterize the weather elsewhere across these latitudes.

In addition to the rather steady winds, the monsoon weather is often characterized by very heavy rainfall, not only in the summer when blowing onshore but, in some cases, in the winter after crossing expanses of open water. I experienced drenching winter rains along the east coast of Malaysia resulting from winds crossing the Gulf of Thailand.

The effect of the monsoon winds on the currents of the Indian Ocean is

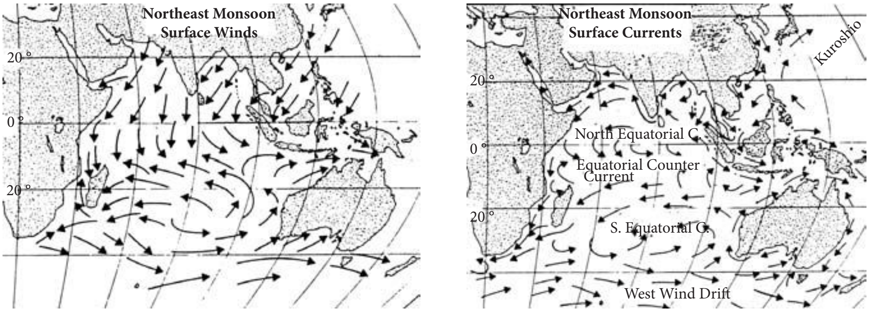


Fig. 14. Northeast monsoon: November through March.

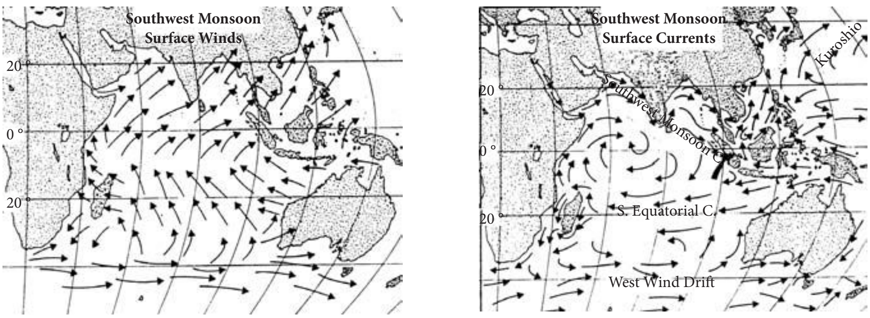


Fig. 15. Southwest monsoon: May through September.

rather complex as is illustrated in the two accompanying figures. (Fig. 14, 15). As you would expect, sailors engaged in trading in the region often take advantage of the seasonal monsoons, sailing south in the winter and returning in the summer.

While it is very difficult to forecast the weather, the ability to do so has advanced considerably. With information from satellites, forecasting has taken great leaps forward in recent decades. The VHF radio transmissions, on which so many of us depend, are obviously enhanced by satellite observations. Various other weather information systems for use on vessels at sea are developing so fast that anything written now is bound to be outdated by the time this is printed.

Rather unique is the voluntary contribution of Herb Hilgenberg. Basically Herb is in touch with several vessels for reports on their immediate surroundings. If you tune in on his broadcasts on 12359.0 megahertz at 20:00 Universal Time (Greenwich Mean Time), you should be able to catch his advisories which are now greatly expanded but continue to describe conditions where the vessels he contacts are underway.

Of course, there are companies skilled in the business of providing weather information for those who feel the need to contract for their services.

All advisory services not withstanding, you will sometimes be anticipating the weather developments more on your own. Certainly you are not going to calmly wait for a radio warning when there are threatening signs of a thunder squall. Furthermore, if you are not in an area covered by weather broadcasts, you may have to be independent in anticipating local conditions. One rather easy trick is to locate threatening thunderstorms on the radar screen. Fortunately, broadcast information with respect to large scale weather developments, such as tracking tropical cyclones, is generally available no matter where you are.

Referring to cloud types, the following generalizations apply: stratus clouds are layered, cumulus clouds are puffy, and cirrus clouds are wispy.

Forecasting from cloud formations requires considerable experience. When a warm front is approaching in the Westerlies wind belt, cirrus clouds may be seen followed by various forms of stratus clouds. And a cold front may be characterized by cumulus clouds, some low, some high, and some towering upwards. Booklets picturing such cloud patterns are

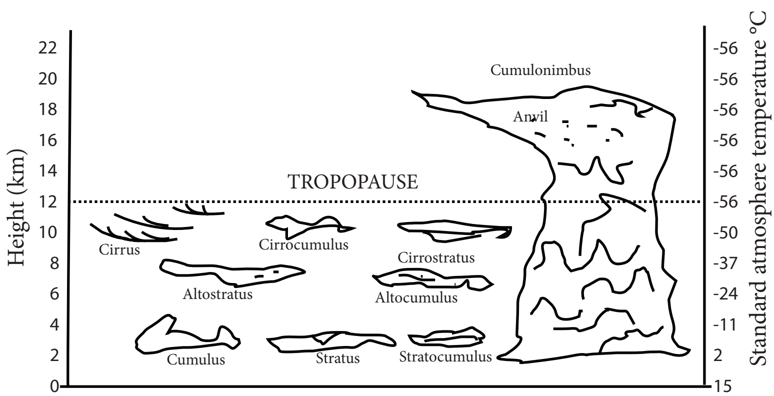


Fig. 16. General cloud types as recognized by the World Meteorological Organization. The Tropopause, shown in the center of the diagram, is between the troposphere and the stratosphere. Here the air ceases to cool at -56.5°C (-70°F), and the air becomes almost completely dry.

Obviously clouds may offer clues as to the weather. So, to help in recognizing the major cloud formations, I include an accompanying sketch plus the following classification of mid-latitude clouds (Fig 16, Table below).

Cloud altitude	Cloud types
High (8,000-18,300 m) (25,000-60,000 ft)	Cirrostratus Cirrocumulus Cirrus
Middle (2,000-8,000 m) (6,500-25,000 ft)	Altostratus Altocumulus Stratus
Low (0-2,000 m) (0-6,500 ft)	Cumulus Nimbus
Clouds extending through all ranges of altitude	Towering cumulus Cumulonimbus

widely available where nautical literature is sold. While these typically imply that they can be used for forecasting, I have never known anyone to do so successfully on a regular basis and, obviously, forecasting from the clouds can not be done under a lingering overcast.

Finally, it helps to be aware of a variety of little clues that indicate the weather. For example, when there is a heavy dew on deck in the morning you know that, at least during the night, the weather has been very favorable. And, when you see smoke rising you know the barometer is high and the weather is stable, whereas smoke sinking downward indicates low pressure and generally unfavorable conditions. Then there are the old sayings that may be meaningful. You have undoubtedly heard: "Red sky at night sailors delight, red sky in the morning sailors take warning." However, when I first typed this the sky was bright red in the morning yet fair weather prevailed throughout the day. You can see that

Fig. 17. Sea smoke forming over open water. Source: U.S. Navy.

the old timers depending on such "rules" would have benefited greatly from modern forecasting.

There are a number of conditions relating to the weather that I have not covered. Let me start with fog, the cloud that lies right at sea level. You can readily understand how the fog sets in, namely it's a matter of the vapor in the overlying air condensing when and where the temperature is below the dew point. Of course, fog is most likely to occur if the air is quite humid or if developing conditions add to the humidity. Conversely, when the air temperature rises above the dew point, as often happens from solar heating during the day, the haze may lift. Also, moderately strong winds will usually clear the air.

One of the many areas where fog is especially troublesome lies along the Great Circle shipping route of the North Atlantic where the warm waters of the Gulf Stream System meet the cold waters flowing south in the Labrador and East Greenland Currents.

A rather unique fog develops when the air just over the water is close to the saturation point and cold air blows in to trigger an effect that resembles smoke sweeping along close to the surface. Appropriately, this phenomenon, mostly seen in higher latitudes, is called sea smoke (Fig. 17). Though all is clear in the air above, this can be a hazard to vessels on the surface and can interfere with the visibility of an aircraft trying to land.

Lightning and thunderstorms, often with heavy rains and gusty winds may occur along the weather fronts discussed above or most anywhere if the air is rapidly rising and an electric potential develops within the clouds, between the clouds, or between the clouds and the surface of the Earth. It is often the towering anvil-shaped cumulonimbus clouds building upward from about 7600 m (25,000 ft) that herald a thunderstorm. In typical cloud to ground lightning the charge proceeds toward the ground in what are called leaders. When a leader approaches conditions that will make a good contact, an upward stroke occurs with a flash of lightning to complete the circuit. This is when the air becomes intensely heated and explodes, creating the thunder clap that you hear.

Counting the seconds between the flash and the thunder that you hear and dividing by 5 will tell you, approximately in miles, how close the lightning is. Generally when lightning is more than 16 miles (25 km) away you probably can't hear the thunder at all but may see the diffuse luminosity referred to as heat lightning. Lightning within a cloud or between clouds may also have quite a diffuse appearance as sheet lightning.

On any vessel it is very common and highly recommended to rig the tallest mast to serve as an elongated lightning rod. A terminal for lightning contact may be mounted at the top. If the mast is aluminum, it serves as a good conductor. If wooden, nothing short of a cable the length of the mast may serve to conduct a lightning strike. The circuit is completed with a cable connecting the base of the mast to a grounding plate or strip providing contact with the water. Incidentally, grounding is much more effective in salt water, a good conductor, than in fresh.

On a vessel with such grounding provisions there is a "cone of protection" from the top of the mast to a surrounding area on the sea surface having a radius equal to the height of the mast (Fig. 18). Though

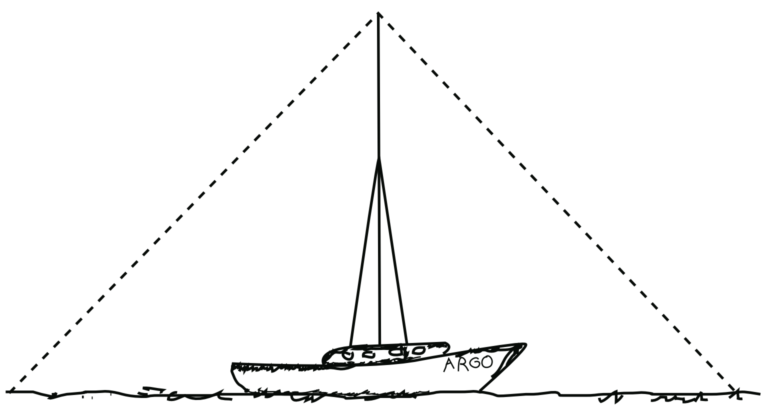


Fig. 18. Cone of protection from a lightening strike. Radius of the cone at its base is equal to the height of the mast.

the probability of being struck by lightning is substantially reduced within this cone, certain precautions are strongly advised. You should not take hold of a mast, a shroud, or a stay. Also, avoid touching with each hand any metal surfaces that might possibly carry an electric charge and shoot it through your body. If it's possible, keep one hand in your pocket, particularly if you are at the wheel, so as to avoid the risk of a two-hand contact.

This brings us to the problem of large voltage differences that, due to lightning, may occur between various conducting materials throughout one's vessel, including the motor, the steering gear, the winches, and much more. Minimizing any damage that may result calls for bonding,

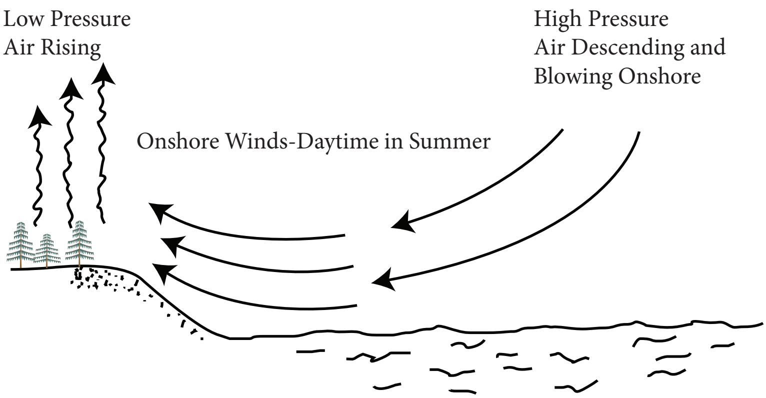


Fig. 19. Daily monsoon showing daytime wind direction. The wind would tend to blow in the opposite direction during the night.

(i.e. electrically interconnecting all such metallic surfaces with a lead to the main grounding provisions). Done properly, this would seem to call for professional know-how though my impression is that bonding is only partially carried out on most vessels. Furthermore, just as you may have a surge protector on your computer at home, you might do well to at least provide such protection for the low voltage electrical equipment on board. And finally, if there is a way to disconnect such equipment when lightning threatens, so much the better. Warning—Don't connect any through-hulls to whatever bonding is provided as this might risk burning a hole through the hull.

The ultimate question is: what do you do if caught in a lightning storm while out on the water in a canoe, a kayak, a rowboat, or a skiff that can't readily be rigged with even the minimum of lightning protection? Hope for the best is the only answer I can think of. And the odds are probably in your favor.

Finally, bear in mind that CPR has saved numerous lives following lightning strikes and other electrical shocks. It's reassuring to have CPR training or to have someone with you who is suitably trained. By the way, don't be in the water when lighting threatens. Sea water is a good conductor and even freshwater (other than laboratory distilled sources) will conduct electricity to some extent.

We have already discussed the large-scale seasonal monsoons of the Indian Ocean area. Not to be overlooked are the familiar daily sea breezes of the coastal areas. (Fig. 19) The cause and effect of a daily monsoon is the same as for a seasonal monsoon except that a daily rather than a seasonal air pressure differential is involved as shown in the

Fig. 20. USCG Healy. *This is the largest of the icebreakers, having been built to serve both as an ice breaker and as an Arctic oceanographic research ship. The hull color is solid red which is customary for ice breakers of the U.S. Coast Guard fleet. Source: NOAA.*

accompanying illustration. Accordingly, the daily sea breeze is a rather local phenomenon. In sailing off the coast of New England in the summer I found that, when the weather was quite settled, one could almost set the clock by the daily sea breeze. A light onshore seabreeze started about 10 A.M. Daylight Saving Time; it freshened through most of the afternoon; and it began to wane an hour or so before sunset.

The discussion of sea ice and icebergs has been left until last, partly because, unlike the effects we have been considering, climate rather than recurrent weather is involved. Because salt content lowers the temperature at which ice will begin to form, sea water, which generally has a salinity of about 35 ppt, will not begin to freeze until the water temperature drops to around -3˚C. On freezing, the dissolved salts are expelled. With rapid freezing this expulsion is incomplete; however, if the ice forms slowly enough or if it has aged sufficiently, sea ice can be almost salt free and even suitable for melting and drinking.

Since water becomes lighter just as it begins to freeze, ice floats on the surface as it forms. (Try to imagine what our polar environments would be like if, as with most fluids, water became more dense as it solidified.) Slush rather than firm ice may develop first. This is often followed by firmer pieces known as pancake ice which may then coalesce to form a

Left: Fig. 21. Fridtjof Nansen. Courtesy Frammuseet, Oslo, Norway. Right: Fig. 22. Fram in pack ice. Courtesy Frammuseet, Oslo, Norway.

more continuous sheet.

Before the recent global warming, freezing in the Arctic resulted in ice some 3 to 5 m (~10 to 16 ft) thick making it practical to have manned research stations on the surface. Unfortunately, from the standpoint of traveling across the surface or being free of damaging conditions that might develop, large scale merging and drifting effects have resulted in hummocks and ridges in the Arctic Sea and in the rim of ice around the Antarctic Continent. Also, there is a lot of movement of the ice fields with shifting open areas as a result. Furthermore, with global warming the ice cover is becoming thinner in the Arctic Ocean and has receded around the periphery during successive summers. Accordingly, I am told that the Canadian government is stepping up its patrol of waters to the north in anticipation of greater shipping and fishing activity. Explorers of old looking for a Northwest Passage were born too soon. Will the Panama Canal become obsolete!?

While there have always been ships operating in the higher latitudes during the warm months when the ice is broken up, vessels so involved are typically moved to safer waters with the onset of winter. If a vessel is caught in the ice, any damage that results may be negligible provided the hull is strong and is not stressed by massive, moving ice flows. Thus, those on board have the option of calling for assistance from an icebreaker or waiting for the following summer thaw.

Modern icebreakers are so massive and well designed that they can easily crush their way to the North Pole (Fig. 20). Actually Russia has been using *Yamal*, one of its nuclear powered icebreakers, to take tourists to 90˚ N. Much of the time, icebreakers are on more routine service operations, opening up sea lanes and ports, and, in the Antarctic, servicing research stations on the continent.

I have always been fascinated by the achievements of Fridtjof Nansen, a Norwegian explorer/scientist and, later in life, an outstanding international diplomat focusing on refugee crises (Fig. 21). One of his great ventures involved intentionally running *Fram*, a rugged and reinforced ship, into the ice north of eastern Siberia (Fig. 22). From wreckage that had drifted on the polar ice cap from Siberia to Greenland, it was quite well known that there is a drift from east to west. So the voyage of *Fram* was a bold experiment to see if the Arctic ice flow would carry a rugged ship to the North Pole, or at least near the Pole. Though *Fram* did not drift as far north or west as had been thought possible, very

Fig. 23. Nautilus, *the first nuclear submarine. On August 3, 1958* Nautilus *was also the first submarine to travel extensively under the ice and actually reaching the North Pole. Source: U.S. Navy: Submarine Force Museum.*

Fig. 24. Iceberg off Antarctica grounded in the Ross Sea, Antarctica. Source: NOAA.

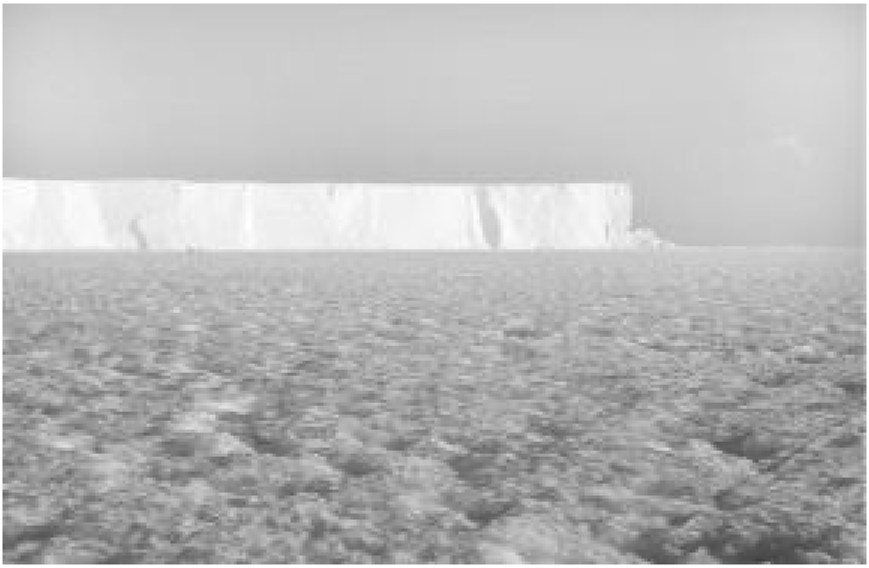


Fig. 25. Table iceberg grounded on the Ross Sea off the Antarctic. Source: NOAA.

valuable observations were made. Furthermore, since *Fram*, after being driven into the ice north of Siberia in 1893, broke free near Spitzenbergen three years later, more information had been obtained regarding the flow in these northern waters. A late addition to seek a drift is the expedition funded by the European Union along with several European laboratories and involving the schooner *Tara*. *Tara's* course was somewhat similar to that of *Fram* but the drift was closer to the North Pole and the transit took only five months. Being the focus of a modern cooperative undertaking, the overall expedition encompassed a broad spectrum of observations.

The ultimate in travel in the Arctic is the practice of transiting under the ice with nuclear submarines. In the early 1930s this had been attempted using an older, diesel-powered sub which was given the name *Nautilus* for this venture. Though this early attempt didn't get very far, some useful data were obtained. However, modern nuclear powered subs have little difficulty traveling submerged in the Arctic, and they can readily surface in openings or by penetrating through the ice cover to make added observations. In 1958 a nuclear sub, also named *Nautilus*, made the first extensive voyage under the Arctic ice shield (Fig. 23).

Should your travels take you to the west and east coats of Greenland you would encounter endless fields of icebergs (Fig. 24). These are the progeny of the Greenland ice cap which is one mile (almost 2 km) thick and may calve as many as 10,000 to 12,000 bergs a year. The southward flowing Labrador and East Greenland Currents carry these into the Great Circle shipping lanes. As almost 90% of an iceberg is below the surface, a close approach can be dangerous. Dense fog, common in the North Atlantic as mentioned above, adds to the danger. These are the conditions that spelled the doom of the *Titanic* and which subsequently led to organizing the International Ice Patrol carried on by the U.S. Coast Guard.

Icebergs are also abundant off the shores of the Antarctic Continent where (Fig. 24) there is a considerable accumulation on the shelf before the bergs float free. This is not only the source of icebergs of moderate size but is the origin of enormous so-called table icebergs which can be as large as the State of Connecticut and may have a life span of several years (Fig. 25).

Since the ocean circulation around Antarctica minimizes any northward drift of icebergs and there is little shipping in the region, the concern with respect to icebergs is not as great as for the North Atlantic. However, since icebergs may occur wherever there are continental glaciers moving toward the sea, the southern coast of the Alaskan Peninsula must be included in any summary of areas where they are common offshore.

I would prefer to end this chapter without mentioning the Bermuda Triangle but, since there are those who insist on breathing life into unfounded fantasies, I must discuss this supposed mystery.

The supposed Bermuda Triangle is bound to the north by a broad band that runs from the East Coast of Florida to Bermuda, then turns south to Puerto Rico, and finally runs westward back to Florida. There are stories of ships and airplanes having been lost within this expanse and the fact that many of these remain unaccounted for has led to the suggestion that the seas and the overlying atmosphere may be operating in strange and mysterious ways. Accordingly, some suggest that travel through the region can be unusually dangerous.

Actually, the Triangle is very heavily traveled. For example, airplanes departing from Miami for the Northeast or toward Europe regularly fly right out into the region. I have flown to the Northeast from Miami many times and have observed that the plane swings off to the East and continues on over the Bahamas Banks. Also, from the air I could see considerable south- and north-bound shipping traffic when my plane flew over the Triangle.

Conditions within the Triangle are not really a mystery. The U.S. Weather Bureau has directed considerable attention to the region, especially as hurricanes may travel through the area. The Navy and the Coast Guard are also very active there. Finally, NASA, weighing reliable information I am sure, has established its basic satellite launching track from Cape Canaveral right across the Bermuda Triangle.

To be sure, numerous tragedies have occurred in the Triangle. While many have been unaccounted for, this is not unique for travel at sea in general.[1]

Less familiar to those in the Western Hemisphere is the supposed Dragon's Triangle, alias the Sea of the Devil, extending south and east of Japan. The people of the area embellish the stories of tragedies in the Triangle with legends of dragons being involved. It's a Bermuda Triangle story but in a different ocean.

If you choose to emphasize the mysterious—so be it!

1 It is remotely possible, under extremely rare circumstances, that very large quantities of methane gas released from the ocean floor might sufficiently lower the buoyancy of the water under a ship to cause it to sink. And there are those who believe this may account for some of the sinkings in the Bermuda Triangle and even may have caused certain airplane tragedies as methane gas reached the atmosphere. However, there is no reason to believe that this remote possibility is more likely to occur in the Bermuda Triangle than elsewhere on the high seas.

Chapter IX. Plankton, Nutrients, Productivity, and the Color of the Sea

A jar of seawater may appear very clear though, almost certainly, it is teaming with microscopic life (Fig. 1, 2, 3). The key component of this life, much smaller than anything the human eye can see, is the drifting one-celled plant life, known as phytoplankton and containing chlorophyll. Using light energy from the Sun, in a complex process referred to as photosynthesis, chlorophyll serves as a catalyst in capturing

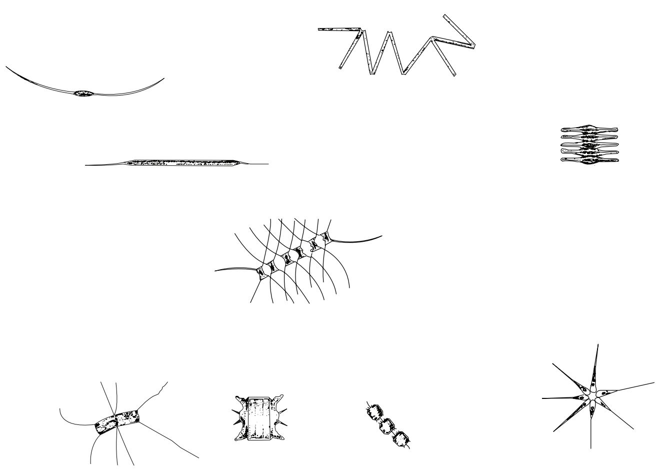


Fig. 1. Diatoms: Representative phytoplankton as seen under a microscope. Modified from Wood, R.D. and J. Lutes. 1968. Guide to the Phytoplankton of Narragansett Bay, Rhode Island. The Kingston Press, Wakefield, R. I.

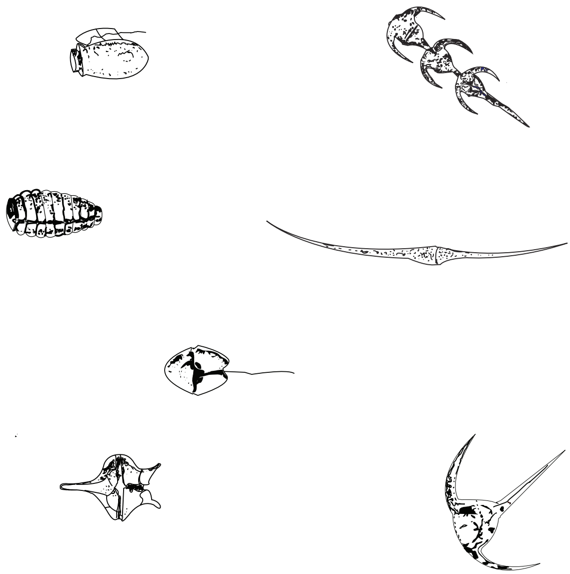


Fig. 2. Dinoflagellates: Representative phytoplankton as seen under a microscope. Modified from Wood, R.D. and J. Lutes. 1968. Guide to the Phytoplankton of Narragansett Bay, Rhode Island. The Kingston Press, Wakefield, R. I.

the solar energy to form carbohydrates and release oxygen from carbon dioxide and water.[1]

$$\mathbf{6CO_2 + 6H_2O} \underset{\text{chlorophyll}}{\overset{\text{solar energy}}{>>>>>>>>>>>>>>}} \mathbf{C_6H_{12}O_6 + 6O_2}$$

The carbohydrates combine with nitrogen and phosphorus in solution to form additional organic components as needed to support a growing phytoplankton population, thereby providing the base of organic life in the sea.

Respiration is the reverse of these synthetic processes as phytoplankton are oxidized and the stored energy becomes available. Accordingly, in natural communities that are in balance, there tends to be ample oxygen during daylight when photosynthesis prevails while, due to respiration, oxygen levels may be lowered during the dark or at depths beyond the

1 This reaction will be referred to again in Chapter XVIII regarding the role of phytoplankton in offsetting the increase of atmospheric carbon dioxide that causes global warming. It is also mentioned in Chapter XVI with respect to the role of the symbiotic algae, the zooxanthellae, embedded in the tissue of corals.

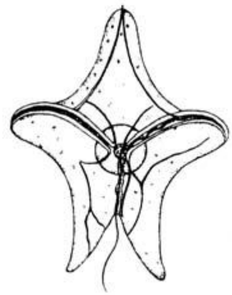


Fig. 3. Greatly enlarged drawing of a typical dinoflagellate. Drawing by Debbie Kennedy.

penetration of light. (Of course, balance is not always achieved. We will be discussing situations in which oxygen is depleted, sometimes quite naturally in the cycling of organic matter and sometimes due to pollution.)

Phytoplankton is abundant in both marine and freshwater environments. You can think of it as a floating pasture which is grazed upon by a wide variety of drifting animal plankters, (i.e. the zooplankton that are also very small).

In the past, typical food chains or consumer pathways, starting with the production of the phytoplankton, were often portrayed as follows:

phytoplankton > zooplankton > larger zooplankton or small fishes > larger fishes> the latter being harvested by humans where fisheries are involved

Increasingly, we have become aware that some of the phytoplankton production is not directly consumed by zooplankton but is first cycled through a very complex web of microscopic organisms including bacteria. Recognizing the cycling that is taking place en route from the primary productivity to larger consumers and the further cycling among the consumers, we now tend to use the term *food web* rather than *food chain*. Furthermore, ecosystems may vary with respect to the species that make up such food webs.

Since collecting and studying the microscopic planktonic life requires specialized nets (Fig. 4), a good microscope, and some instruction, the subject of plankton tends to be beyond the scope of this book, which focuses on observations made with only the simplest of equipment. Even so, the accompanying illustrations of a few representative diatom and

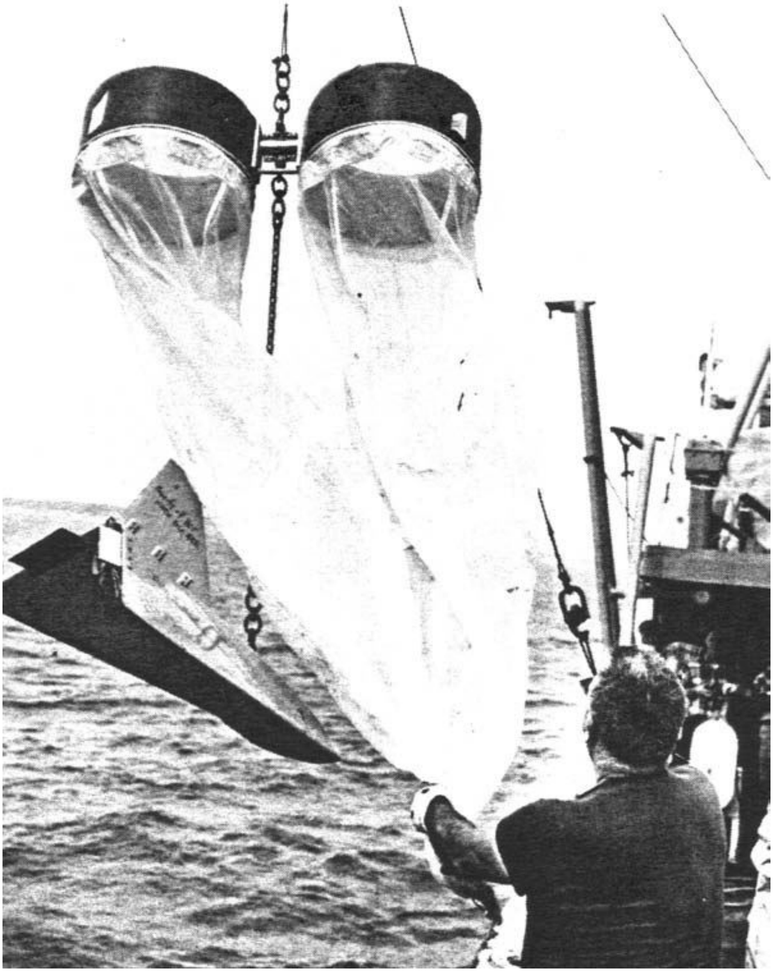


Fig. 5. A pair of plankton nets. When mounted in this way, they are referred to as bongo nets. Source: National Marine Fisheries Service.

dinoflagellate plankters should provide some insight as to what these microscopic forms are like. Furthermore, references to the world of the plankton are given at the end of this chapter, and some suggestions are listed as to where one can purchase inexpensive nets to collect plankton by towing such a net slowly when underway. (An added note describes how a crude homemade plankton net can be made out of nylon hose and a wire clothes hanger.)

Since many zooplankton species migrate to the surface at night, you may be able to collect an interesting sample by using an ordinary fine-meshed aquarium net. No matter how they are collected, the larger zooplankters may be seen, at least as conspicuous specks, with a good magnifying glass. If you are in the North Atlantic, the copepod, *Calanus finmarchicus*, will be in the mix of the specks you are looking at and, since the adults can grow to almost 1 cm (though less than 1/4 an inch), you may recognize them. (See numbers 15 & 16 in the accompanying illustration of mixed plankton (Fig. 5).) Much larger, and very easy to see, are the various species of krill, many being as long as one's thumb (Fig. 6). While widely distributed throughout the oceans, krill are especially abundant in Antarctic waters.

The copepods and the krill are representative of the zooplankton that is very important as food for various plankton-feeding species including, of course, many fishes and whales.

Finally, there is one phytoplankton, namely *Trichodesmium*, that can actually be seen both because of its red color, especially noticeable in the Red Sea, and also because its cells clump to form conspicuous tuffs and puffs (Fig. 7). *Trichodesmium* is widespread in the surface waters of the tropics and subtropics and is especially important as it supports phytoplankton productivity by converting gaseous nitrogen (N_2) into accessible dissolved inorganic nitrate.

The penetration of light into the water column is often among the measurements taken by oceanographers since this indicates how much energy from the Sun is available to drive photosynthesis and the growth and productivity of the phytoplankton. (See Chapter X.) In addition, oceanographers study the concentration of nutrients needed for productivity, particularly those available in limited quantities. Accordingly, much of this research is directed toward determining the levels of phosphorus and nitrogen mentioned above as essential for the ultimate synthesis of living organic matter. Also, because of the special

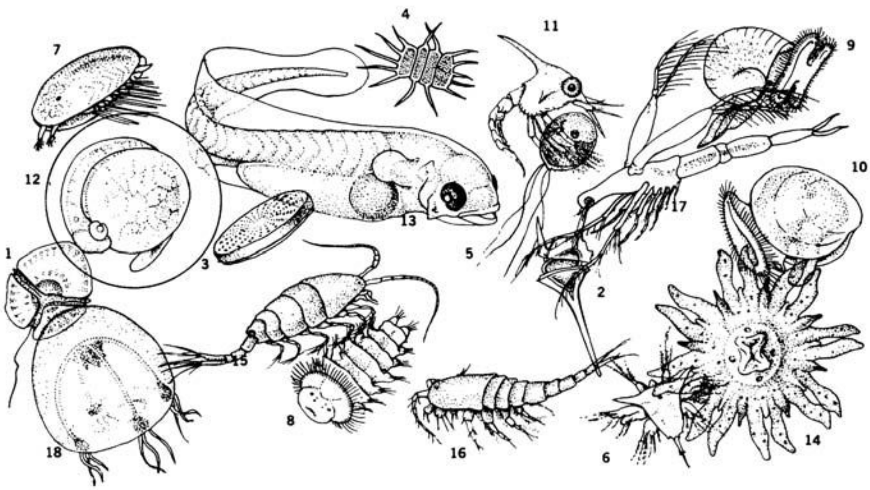


Fig. 5. Representative Plankton

- ***Numbers 1-5 are phytoplankters, none of which can be seen without a microscope: 1 and 2-dinoflagellates, 3-diatom, 4-chlorophyte, 5-chrysophyte.***
- ***Numbers 6-10 are zooplankters that cannot be seen without a microscope: 6- barnacle larva , early stage*, 7-barnacle larva, later stage*, 8-worm larva*, 9-snail larva*, 10-oyster larva*,***
- ***Numbers 11-18 are zooplankters that can just be discerned without a microscope: 11-crab larva*, 12-typical fish egg showing larva, eye and yolk*, 13-striped bass larva as found in the Chesapeake Bay or the Hudson River*, 14-jellyfish just after strobilation*, 15 & 16 typical pelagic zooplankters, 17-water flea, 18-small jellyfish of a group called hydromedusae.***

Those marked with an asterisk (*), for example the oyster and the crab larvae, are the planktonic larval stages of species more familiar as adults. (Drawings by A.J. Lippson.)

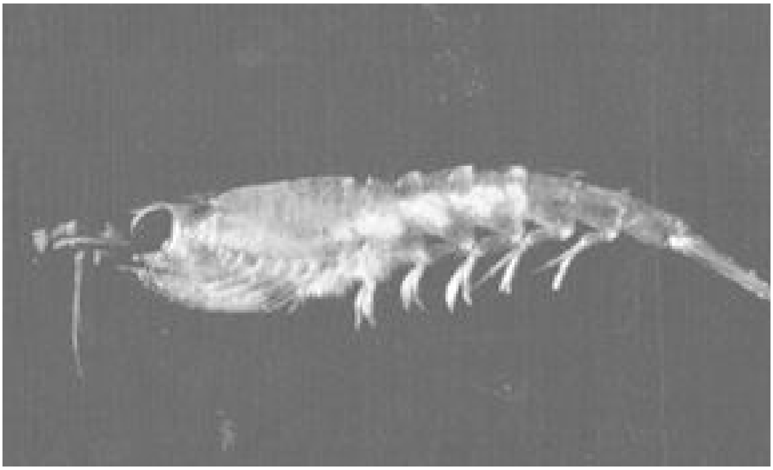


Fig. 6. Krill, enlarged. Courtesy of Jamie Gomez-Gutierrez.

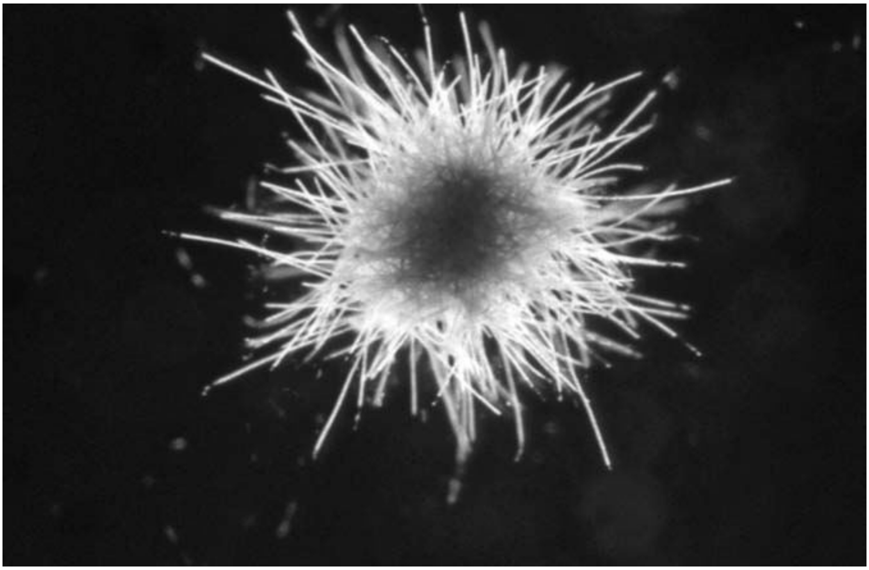


Fig. 7. Trichodesmium. Source: John Waterbury, Woods Hole Oceanographic Institution.

need of diatoms, which are cells encased in glassy (silicate) capsules, attention is commonly focused on silicon as well.

Additionally, trace elements, so-called in view of the very small, yet critical, amounts involved, are sometimes the focus of sampling at sea. Iron is a good example of a trace element. Most areas receive a sufficient supply of iron from the continents, including quantities in the dust blown thousands of miles downwind. However, there are vast expanses of the ocean where, though there is an ample supply of phosphorus and nitrogen, any increase in the phytoplankton population may require more iron. Aware of this, oceanographers have been experimenting at sites in the Pacific and Southern Oceans by adding soluble inorganic iron compounds and observing the increase in phytoplankton productivity that results. Of interest is the possibility that, if iron were to be added on a grand scale, a substantial increase in phytoplankton, with the accompanying increase in photosynthesis, would draw down some of the carbon dioxide in the atmosphere which is accumulating and causing global warning. (See the end of Chapter XVIII on Pollution.) Caution is needed! There are many unknowns that must be resolved before undertaking the practice of seeding areas with a trace element.

Offshore banks mixing nutrients into the water column tend to be quite productive of phytoplankton and may support important fisheries. Favorable currents may also serve to enhance mixing in regions that are not so shallow. Most impressive are areas where there is a process known as *upwelling,* which brings enriched deep water to the surface, resulting in cool, nutrient-enriched conditions (Fig. 8, 9, 10).

Upwelling may occur where there is an Ekman transport of water away from the coast. (See Chapter V.) In the Southern Hemisphere, this develops where the coast is to the right of the prevailing current as is the case off the west coast of South America. This was discussed in some detail in the Addendum to Chapter VI where upwelling predominates although it is often interrupted by El Niño. In the Northern Hemisphere, upwelling may take place where the coast is to the left of the prevailing current as happens during summer off the Northwest Coast of the United States and Canada. In the Pacific, some upwelling also occurs along the Equator where there is a belt of divergence as the currents generated by the westward-blowing Trade Winds are subject to Ekman transport off to the north and to the south.

One of the greatest areas of surface divergence and consequent upwelling is linked to currents close to the Antarctic Continent. This accounts for the fact that krill are so very abundant there. And it was the krill that accounted for the large-scale whaling operations near Antarctica in times past. Ultimately the whale populations became over-harvested but, fortunately, whaling there and elsewhere was greatly curtailed under a moratorium adopted in 1986. (See Chapter XII.) Other than the recovering whale populations, consumers depending on the krill include enormous colonies of penguins. Also, by some estimates, the seal rookeries in the surroundings of the Antarctic are so productive that the population of these mammals equals the numbers in the remaining areas of the oceans. Attempts to develop a fishery based on krill in Antarctic waters have not been very successful.

Some Areas Noted for Upwelling:

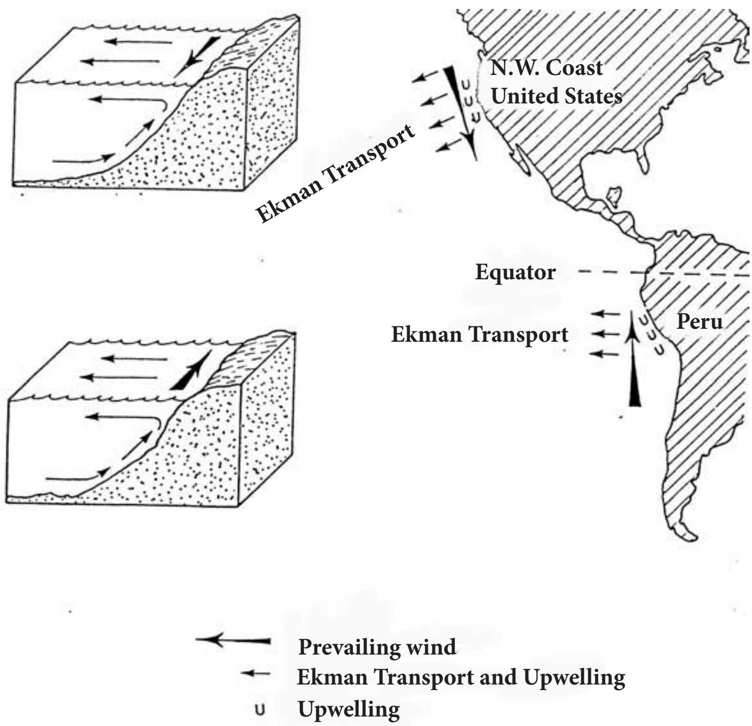


Fig. 8. Upwelling such as occurs off South America due to the Peru Current and off the Northwest Coast of North America when the wind is out of the north.

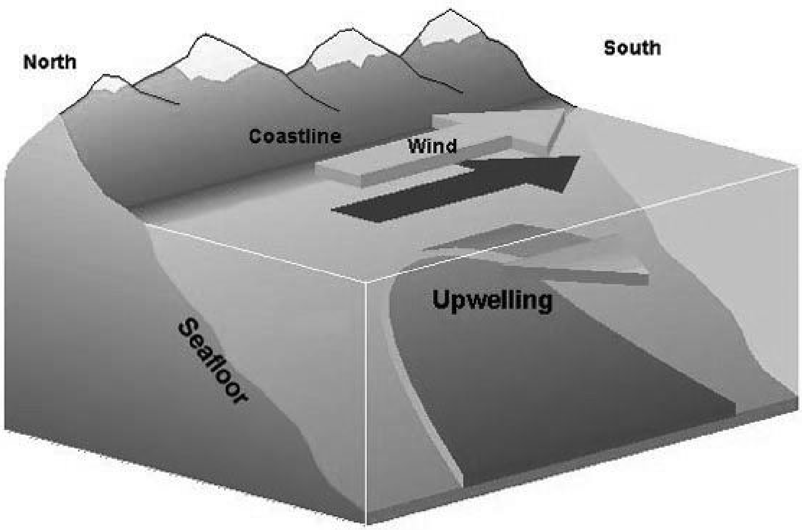


Fig. 9. Diagram demonstrating upwelling. Source: NOAA.

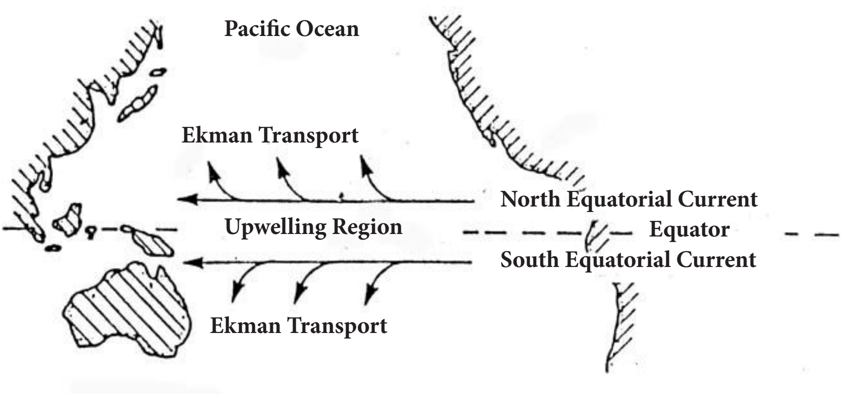


Fig. 10. Upwelling along the equatorial belt where divergence occurs as Ekman transport causes the flow to drift off to the north and off to the south.

- Off the West Coast of Peru, Ecuador, and Central America
- Off the West and Northwest Coasts of North America
- In the divergence areas of the Equatorial Pacific
- Off the Western Bulge of Africa
- Off the Southwest Coast of Africa
- East of the Horn of Africa
- In the Antarctic

The effect opposite to upwelling, namely downwelling, may prevail in certain areas and during certain seasons. For example, downwelling may occur off the coast of Oregon when, in contrast to the summer conditions, winds from the south are more common (Fig. 11).

This discussion of nutrients and plankton leads to comments regarding the color of the sea. Often any color effect is subdued if present at all. It's generally quite drab at night when the surface may have a slate gray or even black appearance. However, in the daylight on the high seas, varying effects are often largely related either to the abundance or relative scarcity of phytoplankton resulting from varying supplies of nutrients.

As the sun shines on clear waters, low in nutrients and with sparse plankton populations, the short blue wavelengths penetrate and reflect off the molecule-size particles in the water column while the reds, the greens, and the yellows are absorbed. The result is the well known *deep blue sea effect*. Areas where this is especially pronounced, as in the central gyres of the major ocean circulation systems, are often referred to as the deserts of the sea. While the Sargasso Sea of the North Atlantic is a good example, you may experience this characteristic blue most anywhere at sea if the water is comparably clear. The effect has been compared to the blue of the sky on a clear day, the explanation being much the same. Furthermore, on the high seas the reflection off the sky may enhance the blue effect.

A related effect may be experienced in clear nutrient-poor water in the shallows of the tropics where, with the reflection off the white carbonate sediments, the blue assumes lighter, turquoise shades.

In nutrient-rich waters, on the other hand, the abundance of plankton may be sufficient to reduce the clarity of the water. Reduced clarity is most common in enriched coastal areas due to the flow off the land, out of the estuaries, and the effective mixing of water including upwelling when present. But it may also be experienced on the high seas such as in the diverging, upwelling waters of the equatorial belt or during the spring phytoplankton blooms of the North Atlantic.

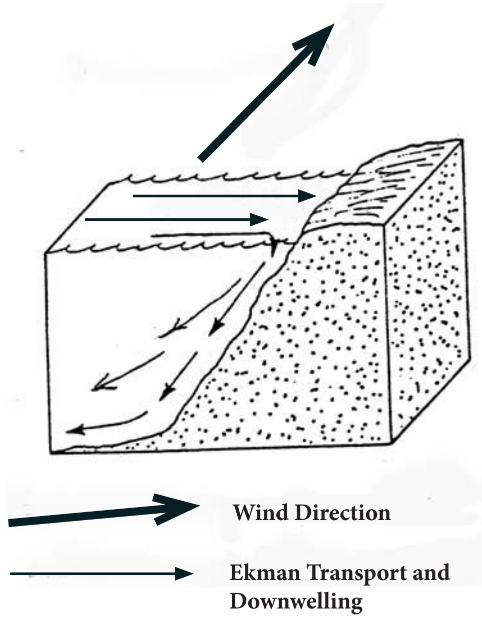


Fig. 11. Downwelling.

Where the concentration of the phytoplankton is sufficient, reflection off the cells may actually color the water. In the case of extremely high concentrations of certain species, dense blooms of colored water may occur. Such unusual blooms are generally lumped under the heading of "red tides" though the water may appear brick red, brown, yellow, or even white, depending on the species involved (Fig. 12, 13). (For more on blooms, some of which may be toxic, see the discussion in Chapter XVIII on pollution.)

For the whole story of what may affect the color of coastal water, one must take into account various organic and inorganic compounds in solution or in suspension. A yellowish appearance may be brought about by dissolved organic matter that is exuded by the phytoplankton or transported from land. In addition, there may be various other sources of color, including pollutants. Obviously, silt and any other suspended sediment stirred into the water may obscure any color effect.

As you travel seaward from the coast, you might expect any color changes to be gradual. On the other hand, I have been impressed with

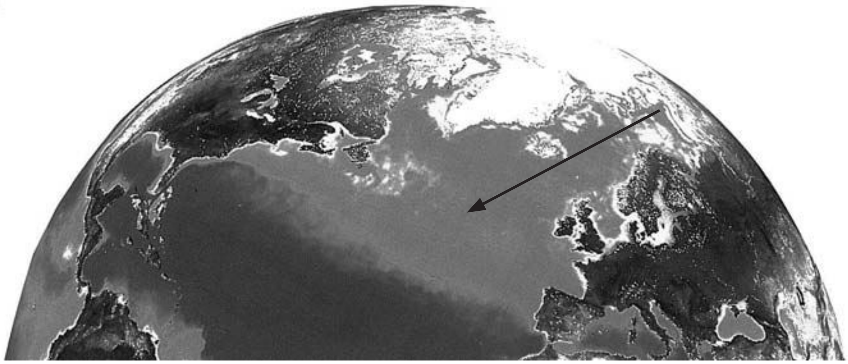


Fig. 12. Spring bloom in the North Atlantic. In this black and white reproduction, the bloom appears as a light gray at the end of the arrow. While generally not as intense as a red tide, this is one of the most widespread changes occurring regularly in the ocean biosphere. The bloom starts north of the Sargasso Sea in March and peaks in May-June. The area may be larger than the Amazon rainforest. Source: NASA/Goddard Space Flight Center.

Fig. 13. Red tide bloom off the California Coast. In this black and white reproduction, the intense red bloom appears white. Source: National Office for Marine Biotoxins and Harmful Algal Blooms.

the sudden transition, that is sometimes experienced when underway, perhaps from a greenish tint off the coast to the prevailing blue of the high seas.

For More Information on Plankton:

The Open Sea: Its Natural History, Part 1. The World of Plankton by Sir Alister Hardy, 1969. Houghton Mifflin, Boston.
(Unfortunately this is out-of-print but it may be found in many libraries and, hopefully, in some secondhand book outlets.)

Coastal Marine Zooplankton, by Todd, C.D., M.S. Laverack, and G.A. Boxshall. 1996. Cambridge University Press, New York.

Most of the general texts written for college courses in oceanography have very good sections on plankton.

Two sources of moderately priced plankton nets are:

Carolina Biological Supply Co.,
P.O. 6010, Burlington, NC 27216

- Plankton net with collecting tubes; made of durable nylon with 153 micromillimeter mesh openings. Cost = approximately $100.

Ward's
P.O. Box 92912, Rochester, NY 14692

- Similar to the above but with a plastic bottle rather than collecting tubes.

Oceanographers use various mesh sizes for sampling and use equipment that enables them to lower the nets and to open and shut them at given depths. For plankton too small to be retained by nets, some collecting may be done by settling or centrifuging samples of water.

Instructions for a Homemade Plankton Net

Materials Needed:
Pair of nylon stockings, wire clothes hanger, wire cutters, pliers, needle and thread or duct tape, small sampling jar (pill bottle or baby food jar), string, strong rubber band.

Construction and Use:

1. Use one leg of the nylons—cut it off just below the crotch.
2. Untwist the clothes hanger; shape it into a circle; and twist the ends together.
3. Pull the cut end of the nylon leg through the wire circle and fold it back.
4. Sew or tape the nylon in place.
5. Cut a small hole in the toe of the nylon and pull it over a sampling jar.
6. Secure the jar with a rubber band or string.
7. For towing, attach a three-piece bridle of strong string to the ring of the net.
8. Tow the net slowly for short distances.
9. After making a tow, remove the jar and pour the contents into a container for study, which, of course, requires a microscope.

Chapter X.
Secchi Disk Oceanography

What can you learn from a small piece of wood painted black and white and dropped overboard until it disappears? Quite a lot actually! I am referring to using what is known as a Secchi disk, which is the simplest of all oceanographic equipment and which provides helpful clues as to conditions in the water column (Fig. 1). Even the most experienced oceanographer may at times find a use for the Secchi disk.

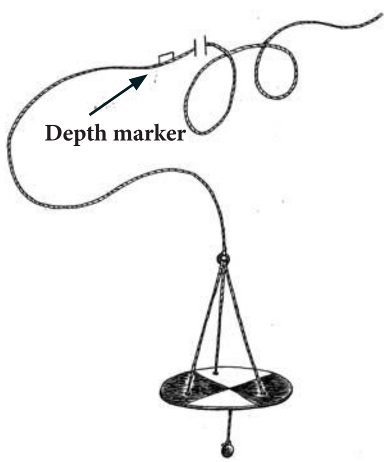


Fig. 1. Secchi disc, the simplest of all oceanographic instruments. Make it yourself! Drawing by Debbie Kennedy.

A Secchi disk is extremely easy to make. All you need is a small flat board (preferably marine plywood), some white paint, some line that will not stretch, and a suitable weight. Standards call for cutting out a circular disk 30 cm (12 inches) in diameter. It must at least be painted white but, to be more elaborate, contrasting quarters of black and white are the preferred pattern. Mark the line from which the disk is suspended to indicate depths in feet, meters, or fathoms.

Now what do you do with this "sophisticated" rig? You lower it over the side, staying clear of any shading from your vessel's hull and noting the depth at which it disappears. Before the development of technically elaborate underwater sensors for light transmission and turbidity, oceanographers used Secchi disk disappearance data to calculate light penetration coefficients. Today the disk may still be used to get an approximate, first impression, of prevailing conditions. For example:

Disk seen to depths of 15 meters (50 ft) or more:
Water is probably nutrient poor with low production and minimal phytoplankton abundance; with very little or no silt in suspension; and with little mixing of deep water toward the surface. Technically, these are referred to as oligotrophic conditions which tend to be characteristic of the deep blue sea or of shallower water if it is also nutrient poor.
Note: There are some situations, as in very nutrient poor waters, in a calm sea and with bright sunlight overhead, where one can see a Secchi disk to depths of at least 50 meters (160 ft).

Disk disappears in less than 2 meters (7 ft):
Light penetration is limited either by high productivity of phytoplankton or by inorganic matter. High plankton productivity suggests nutrient enrichment, either from natural enrichment processes or from pollution. (Observations of your surroundings may suggest whether or not pollution is involved.) If phytoplankton is sufficiently abundant, reflection off these microscopic plants may add a color effect, perhaps green, brown, or red as in red tides. If silt is interfering with light penetration this may be quite evident and can be easily checked by noting the presence or absence of settling in a sample of water.

Disk disappears at around 2 to 10 meters (7 to 33 ft):
Good to average water quality. Available nutrients, though reduced, are apparently sufficient for good phytoplankton productivity but not in such concentrations as to greatly obstruct light penetration.

Obviously, the above categories are somewhat arbitrary and interpretations are most meaningful when there is a distinct contrast in the observations being made. Accordingly, if you wish to compare conditions from time to time, from one location to another, or from season to season, it is important that you only make such interpretations if:

- The available sunlight had been comparable when the observations were made.
- The observations had been made when the sun was fairly high in the sky allowing the light to penetrate effectively rather than being reflected off the surface.
- The reflecting surface of the sea had been about the same when the observations were made; for example, don't compare the Secchi disk disappearance in a rough sea with that in a calm.

Chapter XI.
Seen on the High Seas

In warmer climates you may see the brown alga *Sargassum* drifting by (Fig. 1). You can readily identify it by the bladders in the fronds serving as floats. Each bladder is about the size of a bean. *Sargassum* is Portuguese for *grapes*. Although this light brown

Examples of what you might see on the surface:

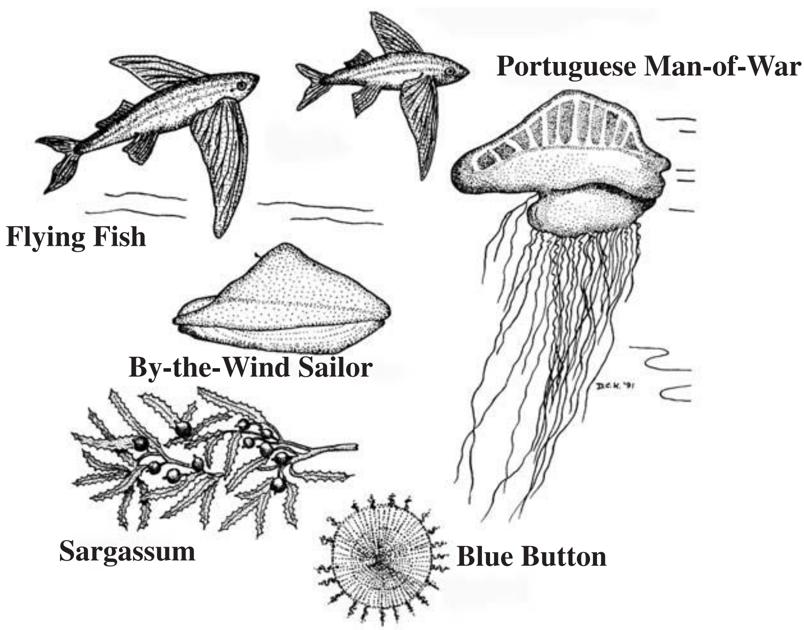


Fig. 1. Seen on the surface. Drawing by Debbie Kennedy

vegetation is often just scattered here and there, it is sometimes aligned in rows as the result of the Langmuir Circulation described in Chapter IV. Grab some with a dip net. Even if you only collect a few fronds, you may find members of a unique community including Sargassum Fish, a specialized Sea Horse, and Gulf Weed Crabs, that make *Sargassum* their home. Actually you might miss these residents at first because they so closely mimic their surroundings in color and physical appearance. In fact, it is said that the Sargassum Fish, with its leaf-like appendages, is so hidden in the *Sargassum* that all you see is it eyes (Fig. 2).

If traveling through the Sargasso Sea, which lies in the mid-Atlantic to the east and south of the Gulf Stream System, you may encounter substantial accumulations of *Sargassum*. Due to the prolonged calms in this area, discussed in Chapter VIII dealing with meteorology, the region is often spoken of as the Horse Latitudes where sailing ships are delayed by the lack of wind. Needless to say when, as can happen, the *Sargassum* gathers in dense rafts, these can further delay the progress of vessels under sail.

Among the most spectacular sights on the surface of the tropic and temperate oceans are the blue floats of *Physalia*, the Portuguese Man-o-War, a colonial siphonophore. The floats of *Physalia* are about 8 inches (20 cm) in length and trail long strings of reproductive and feeding bodies. Stinging cells in these colonies are extremely toxic, yet there is a little symbiotic fish that lives

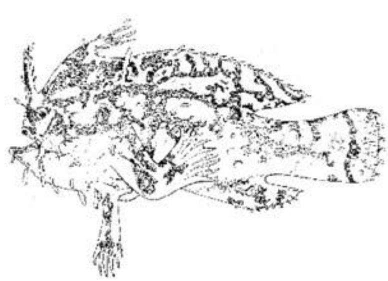


Fig. 2. Sargassum Fish. Source: Fishery Bullletin 74, Fish and Wildlife Service.

Fig. 3. Al Woodcock taking a wind reading while standing in the hydrocage of a research vessel. Courtesy of the Woods Hole Oceanographic Institution.

comfortably in the tangles trailing the floats.

Because my goal is to emphasize the benefits of observing while at sea, I will digress at this point to mention the observations of Al Woodcock (Fig. 3). From the deck and rigging of the Woods Hole sailing research vessel *Atlantis* (Fig. 4), Al noticed that in the Northern Hemisphere the floats of *Physalia* tend to be twisted in such a way that they sail off to the left of the downwind direction of the wind. He then determined, first from museum specimens and later from more observations at sea, that the twist is commonly just the opposite in the Southern Hemisphere. Furthermore, from the work of colleagues, he realized that the vortices of the Langmuir Circulation are asymmetrical and differ from the north and the south of the Equator. According to his drift analysis, he surmised that, to extend the time that feeding polyps of *Physalia* are dragged

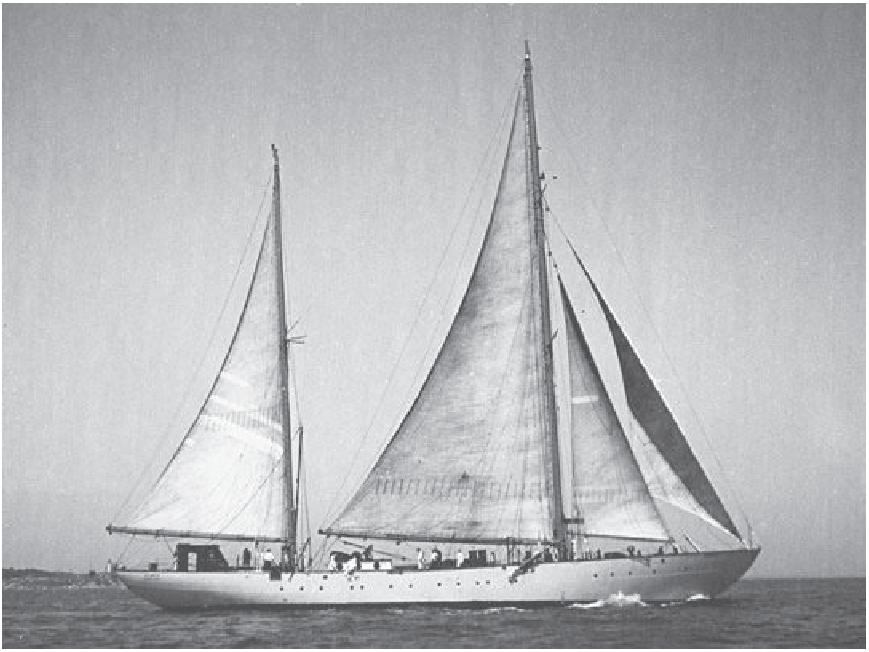


Fig. 4. R.V. Atlantis on a close reach. Atlantis was the first high seas research vessel of the Woods Hole Oceanographic Institution. Launched in Denmark in 1932, she was a 149 foot steel hulled ketch with a powerful auxiliary engine. Courtesy of the Woods Hole Oceanographic Institution.

through the convergence lines of the Langmuir Circulation, the floats must sail differently in the two Hemispheres. (See the accompanying figure with an asymmetrical Langmuir Circulation in the Northern Hemisphere and indicating the contrast between the course of a Portuguese Man-o-War sailing off to the left with that of one sailing to the right with less time in the convergence lines where plankton tends to be concentrated) (Fig. 5).

Woodcock's career, which includes several additional keen observations, is quite interesting. He had been a high school dropout and it is said that he had failed in some 25 jobs before he signed on for the maiden voyage of the Woods Hole Oceanographic Institution's research vessel, *Atlantis*, launched in Denmark and crossing the Atlantic to her home port. Woodcock stayed on at the

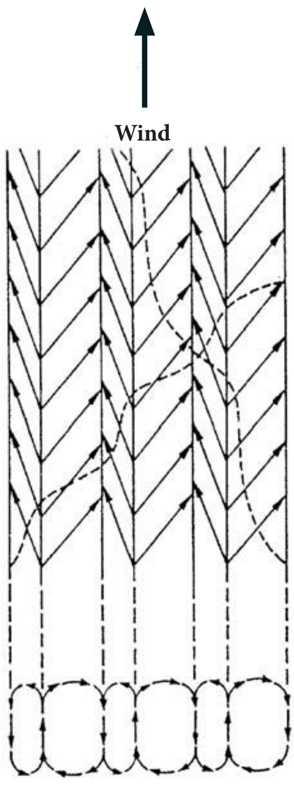


Fig. 5. Diagram showing the assymetry of the Langmuir Circulation vortices as they tend to develop in the Northern Hemisphere. The dashed lines compare a Physalia sailing off to the left with one sailing off the right. Adapted from drawing by Al Woodcock in the Journal of Marine Research.

Oceanographic institution, taking more trips on board *Atlantis* and other research ships, all the while making keen and meaningful observations. As one of his associates wrote: "…he would let nature teach him the subtleties of how it worked."

Eventually Woodstock moved on to the University of Hawaii School of Ocean and Earth Science and Technology and, along the way, was awarded an honorary doctorate. What a career for a high school drop-out!

In addition to the Portuguese Man-o-War, you may see the sails of *Velella*, the By-the-Wind-Sailor, another modified jellyfish but not nearly as specialized as the *Physalia*. They are about 6 cm (2 to 3 three inches) long and each has an upright fleshy sail.

The Blue Button, about 2.5 cm (1 inch) across and looking much as its name implies, is one more floater related to jellyfish that you are likely to see.

Finally, you may see small clusters of Purple Sea Snails, *Janthina*, drifting under the bubbles they secrete for buoyancy.

The blue color of these various species floating on the surface helps to conceal them on the blue sea. But the camouflage is only fair for their coloration is often more brilliant than that of their surroundings. It's as though the adaptation is a bit overdone.

While the Portuguese Man-o-War, the By-the-Wind-Sailor, and the Blue Button are specialized members of the jellyfish group adapted to floating on the surface, there is a varied multitude of other jellies drifting in the water column. Most of these are rather colorless and of a watery consistency. Of those that occur near the surface, the umbrella-shaped Sea Nettles trailing long stinging tentacles are quite common (Fig. 6). Also, you may see Moon Jellies shaped like frisbees or upside down saucers with a ring of very short tentacles around the periphery (Fig. 7). The size range of the Nettles and the Moon Jellies can be quite great. While you may encounter young Moon Jellies shaped just like the adults yet so small that they are hard to see, you may also see some that are considerably more than one foot (30 cm) in diameter.

Diverse though they may be, all members of the jellyfish group have one thing in common, namely the presence of stinging cells, called nematocysts (Fig. 8). For most of the jellyfish, the pain from contact is not likely to be severe though their presence can be quite a nuisance to swimmers. On the other hand, a sting from the tentacles of a Portuguese Man-of-War is extremely painful and contact with the thimble-sized Sea Wasps of the Pacific is downright deadly.

If you are treating yourself for being stung by a member of this group and there are threads containing stinging cells that need to be removed, use a stick or other means to minimize further contact. Then, apply alcohol, dilute ammonia water, methylated calamine lotion, or copious amounts of soap and water. Talcum or baking powder may also help relieve pain. For the severe pain of the Portuguese Man-o-War, medical attention may be necessary. When it comes to those deadly Sea Wasps, your best hope is that you will be adequately warned when they are present, which is common seasonally along certain coastal beaches in Australia, and

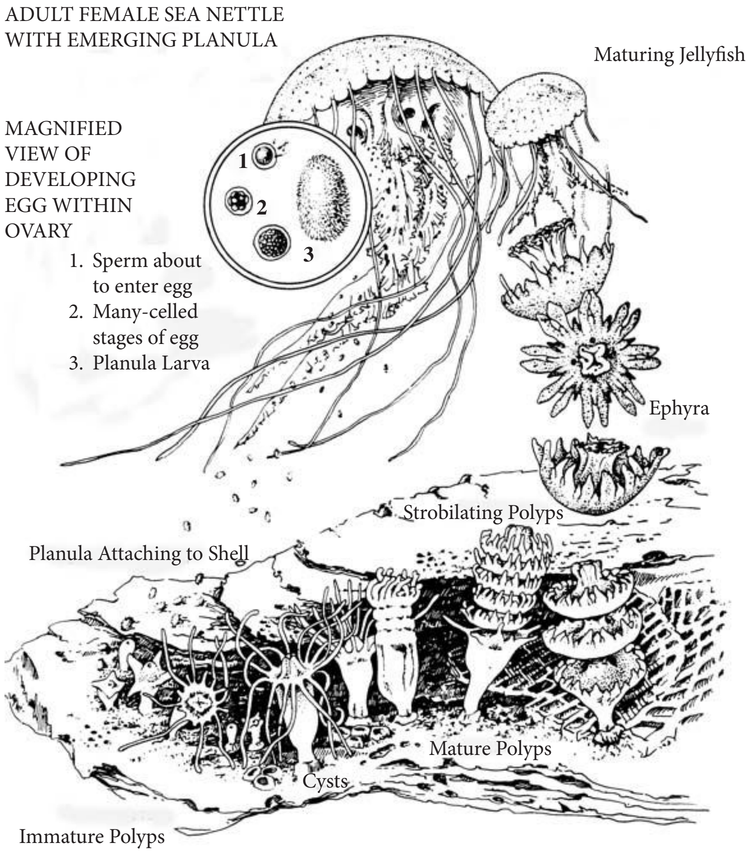


Fig. 6. Life cycle of the Sea Nettle. A polyp stage develops in the bottom environment where it buds off, then comes to the surface as an adult Sea Nettle. In boreal waters, members of this genus grow to several feet in diameter though the form shown here seldom exceeds 6 inches. Drawing by A.J. Simpson.

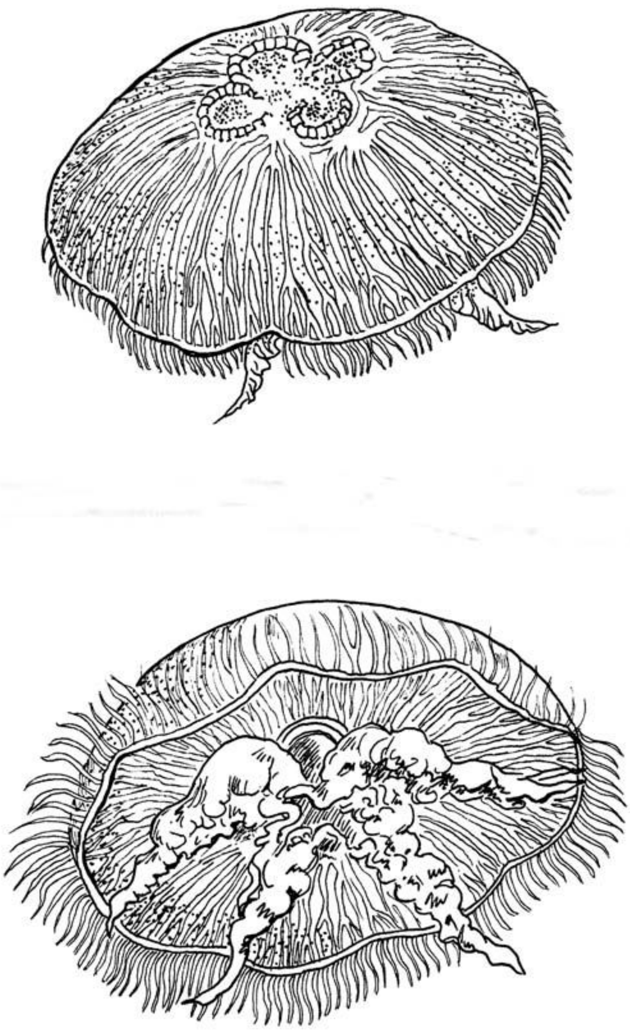


Fig. 7. Views of top and underside of Aurelia, the Moon jellyfish. As is common among jellyfish, this free-floating stage is tiny at first but in some areas they may grow to the diameter of a bushel basket. They are a food delicacy in some regions. Drawings by Debbie Kennedy.

you had better stay out of the water.

Another group near enough to the surface to be seen from on deck includes the Comb Jellies, with flesh similar to that of the jellyfish but lacking stinging cells (Fig. 9).

Comb Jellies are propelled by bands of cilia that may reflect sunlight into the exquisite colors of the rainbow. If you can get a close look, you can see the cilia beating. As will be mentioned below they luminesce at night. [1]

Flying fish are probably the most fascinating of the fishes

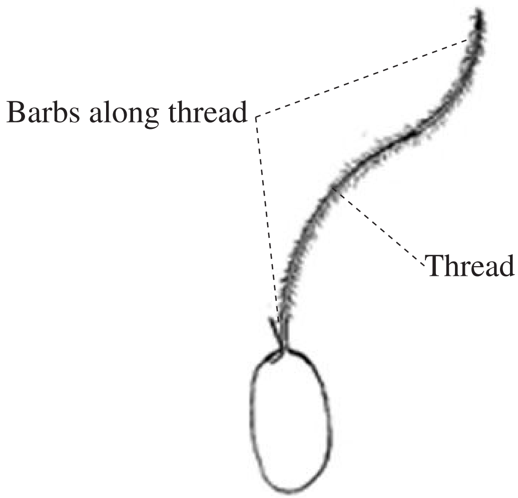


Fig. 8. Schematic diagram of a discharged nematocyst. Before discharge, the long, hollow thread is coiled outside-in within the capsule. Most such threads are open at the tip, presumably to allow the outpouring of a toxin. Mechanical contact with the cnidocil protruding from the contracted nematocyst is one means by which the thread is stimulated to discharge. Nematocysts, in many intricate forms, occur in surface cells called cnidoblasts.

1 Many of the jellyfish and Comb Jellies that you see seem to consist of water and virtually no solid matter. To be sure they may be around 95% water but, for that matter, human tissue runs about 80% water with our blood being around 92% and with the salts in solution somewhat resembling those in sea water.

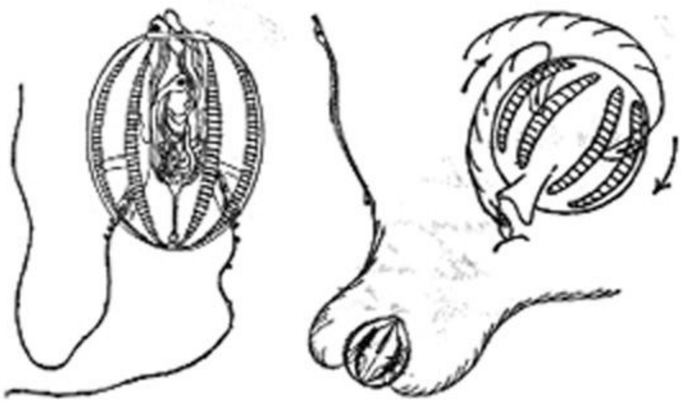


Fig. 9. Comb Jelly. Source: NOAA.

commonly seen at the surface in the tropic and subtropical seas. Though they seem to fly as they break free from the surface, they are, in reality, gliding on their lateral fins which are spread out and stiffened. The gliding distance may be extended as the lower portion of the tail fin is often used to provide an added thrust when dipped into the water. (Keep looking for flight distance records. It's much the same as trying for distance when skipping flat stones from off the beach.)

Fishers often attract flying fish by shining a light on a sheet or something similar. The fish fly into the lighted attraction and drop into the fisher's boat. Your cabin lights may also attract flying fish and you may find some on the deck in the morning. They are good to eat!

Various sharks are common near the surface. Some will be seen swimming on a very steady course with just the dorsal fin breaking the surface. There are many species and most are somewhat similar in overall appearance. One species commonly seen on the high seas is the Blue Shark. This shark is cobalt blue on the back, with vibrant blue on the sides and a relatively colorless underside. It also has a white ring around each eye.The Mako, somewhat smaller, is very dark blue with contrasting white undersides. Other species with distinct color patterns include the Tiger Shark with dark stripes along the back and the Whale Shark which has a pattern of white spots and cross lines on a dark gray background.

An overall dark gray background with lighter undersides is typical of many of the rest of the sharks. Such a contrast, (i.e., a consistently darker or a more intense coloration on the back with lighter undersides), is an effect also commonly seen in whales, porpoises, many fishes and other free swimming inhabitants of the high seas. From above, the darker colors may blend with the animal's surroundings; from below, the lesser contrast blends more with light from above.

Though sharks are also pretty much alike anatomically, there are some notable exceptions. For instance, there is the unmistakable Hammerhead group. Then there is the Thresher Shark with the upper lobe of the tail at least as long as the rest of its body, and the Whale Shark and Basking Shark are giants compared to the rest (Fig. 10). The Whale Shark may reach 14 m (45 ft) or more in length and the Basking Shark is almost as large. These big sharks strain the water for plankton and are unable to devour larger prey.

Other than the two giants just mentioned, there is a rule of thumb that the big sharks are generally the most dangerous. While this is illustrated by the Great White Shark of *Jaws* fame which may grow to as much as 6 m (20 ft) in length, there are a number of other large and potentially threatening species. (See also the reference to shark danger at the end of this chapter.)

Though we know very little about the migratory patterns and associated behavior of sharks, we are becoming increasingly aware that at least some of them may migrate great distances. We do know, for example, that some Great Whites travel from the Coast of California to the Hawaiian Islands. Some of the sharks common near the surface also dive to great depths and there are less familiar species that remain far below the surface.

You are very likely to see the Manta Ray, which belongs to the group of skates and rays, all of which are distantly related to sharks but with their pectoral fins broadly flattened out (Fig. 11). In the case of the Mantas the pectorals have evolved as great wings about

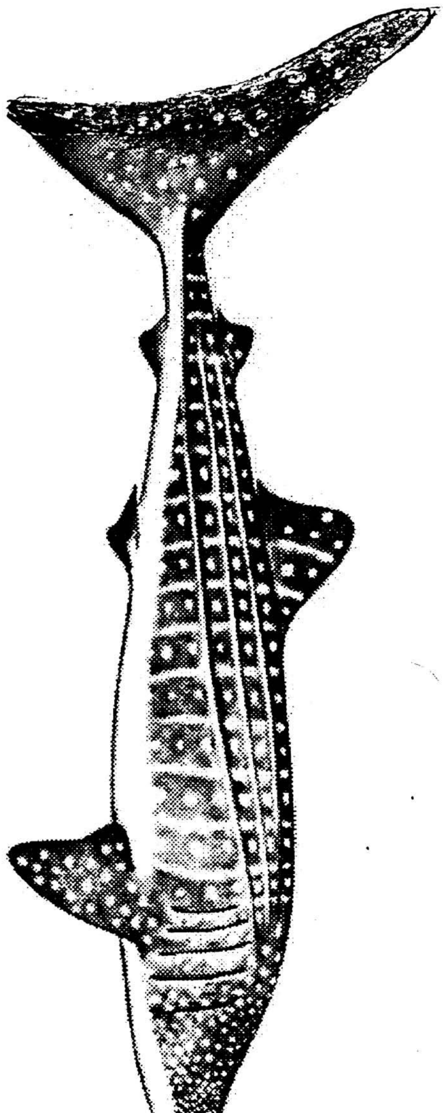


Fig. 10. Whale Shark. Source: Bureau of Commercial Fisheries.

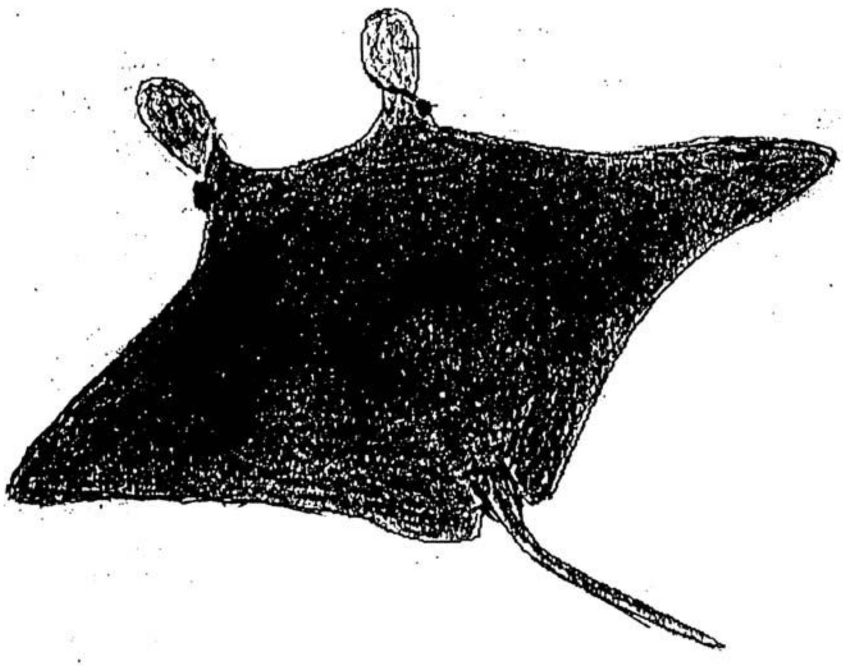


Fig. 11. Manta Ray.

3.5 m (12 ft) across. These huge Mantas wave their large wings as they undulate just below and occasionally break the surface. The lobes anterior to the mouth provide a funnel effect concentrating the plankton on which they feed. The smaller skates and their relatives tend to be near the bottom in the shallows and are not as readily seen by an observer at the surface.

Since many sharks, rays, and skates bear live young, you may witness the birth of their babies where the adults are on display in large aquaria. Some skates deposit egg cases from which the live young are hatched. In aquariums, you will also see that many of the large, free swimming species may have Remoras attached by suckers and getting a free ride with access to food.

The Sunfish or Mola is yet another large fish that may be seen floating just below the surface (Fig. 12). Possibly you will see its towering dorsal fin breaking the surface and flopping back and forth. Or possibly it will be basking, laying on its side. Molas have a bizarre round appearance. One would almost think that the body had been cut off just behind the dorsal and anal fins. The largest Molas may be almost 3 m (10 ft) in length.

At the other extreme, small schooling fish may be seen breaking the surface under suitable calm conditions. Often they are being chased by predators from below. Sometimes, on looking down

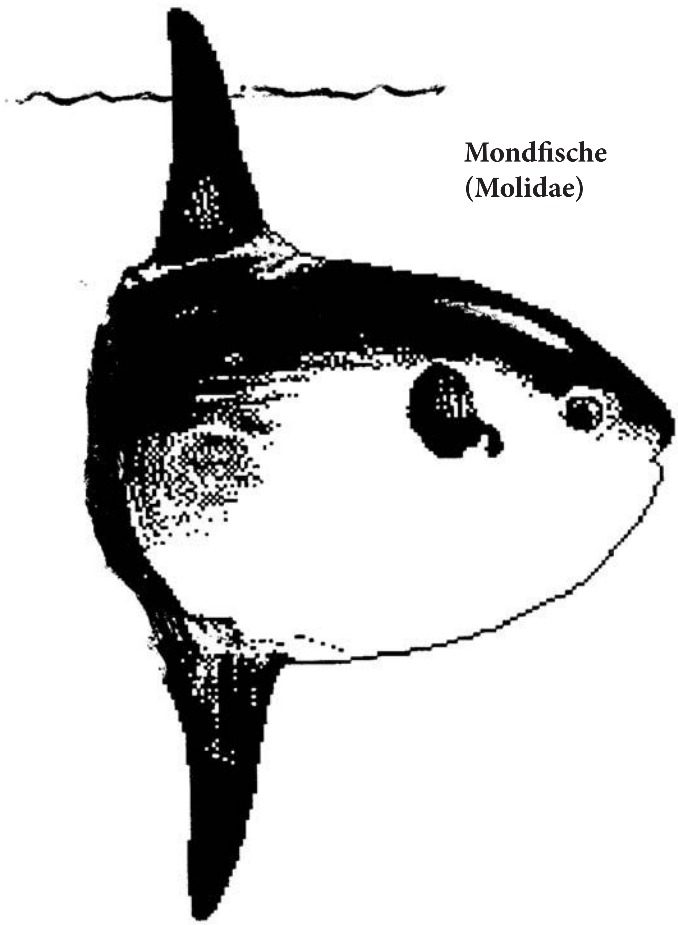


Fig. 12. Sunfish or Mola. Source: NOAA.

from the surface, you can actually observe spectacular fish schools swirling in enormous numbers and in very tight formation. In part, schooling is a defense behavior for it's a bit of a challenge for a predator to single out and capture an individual fish from the confusion of such a tight rotating formation.

Finally, you may also see quite a variety of small fishes feeding on algae growing along the waterline of your vessel. Or, if you happen upon a log that has been drifting for some time and has acquired a rich attachment of marine life, you may not only see the small consumers nibbling away but may find that larger predators from below are attracted to feed on the gathering. This reminds me of a fishing technique I chanced upon in the Philippines where natives were setting out log rafts to attract a gathering of edible fish.

As discussed in Chapter IX, plankton, though abundant, are far too small to be seen with the unaided eye. However, phytoplankton species are often sufficiently concentrated to affect the color of the water and the results can be quite pronounced when and where blooms, such as red tides, occur.

Also, the presence of certain bioluminescent phytoplankton is evident as they give forth living light, bioluminescence, creating the effect of sparkling stars in the night sea. You can add to the effect if you excite the plankton by stirring the surface of the water, perhaps with a boat hook. Fish stirring the water as they swim by can create the same reaction. Luminescence associated with the rows of cells of balloon jellies may attract your attention. The living light emitted by some larger organisms is often produced by microorganisms in the tissues, often in special photophores or similar anatomical structures.

As the efficiency of bioluminescence runs around 99%, it is sometimes referred to as cool light. Ashore it is familiar as the flashing glow of fireflies. In the great depths of the ocean, well below the penetration of sunlight, the luminescence of many organisms is very well developed and probably quite useful with respect to behavior in such total darkness.

As a rule, insects don't belong at sea. You may want to argue

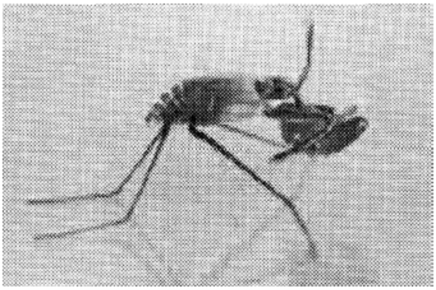


Fig. 13. Halobates, the Sea Skate. The specimen shown is grasping an unidentified food item. Courtesy of Lanna Cheng, Scripps Institute of Oceanography.

Fig. 14. Monarch Butterfly.

otherwise when raided by mosquitoes and other annoyances but that's only when you are close to marshes, beaches and other features of the coastline where such pests may thrive. No matter what the rule however there is always an exception which, in this case, is the Sea Skate, technically known as *Halobate*s (Fig. 13). These are akin to the familiar Water Striders seen on small, calm, freshwater ponds, yet they are very much at home in the warm seas skating along on the film of surface tension, even in fairly rough weather. To lay their eggs, they must find odds and ends of remnants floating on the surface. They have been observed feeding on bits of organic matter on the surface such as zooplankton, dead jellyfish, fish eggs, and larval fish. I don't know of any evidence that they dive for food.

Finally, one may encounter migrating Monarch Butterflies far offshore (Fig. 14). I have seen them 12-16 km (8 or 10 mi) off the coast of Maine. They were heading in the right general direction yet I had my doubts as to whether they would really make it.

Incidentally, when there are plagues of grasshoppers in Africa, it is not uncommon in the Caribbean to see dead and dying grasshoppers blown across the Atlantic Ocean in the Trade Winds or under occasional storm conditions. There is also considerable dust blowing across the Atlantic from Africa. Though, as mentioned in Chapter IX, iron from off the continents is a bonus as a trace element needed for the growth of phytoplankton, there is now some concern that the dust transported is accompanied by a number of pathogenic microorganisms.

Because observations of whales, porpoises, etc., are so fascinating, I have elected to discuss them in a separate chapter which follows. The same is true for seabirds. I have also found it convenient to deal separately with the sea turtles you might see. As to fishes in general, the few mentioned above that might be seen on the surface are but a small and biased fraction of the variety and abundance below. So, in Chapter XIV, I have attempted to provide an awareness of the fishes by discussing the fisheries techniques you may observe in your travels. (Also, since you might get a welcome catch if you use a trolling line, I have included an appendix titled *Trolling While Underway.*)

General Reference for Sharks:

The Book of Sharks by Richard Ellis 1976. Grossett and Dunlap, New York.

Addendum: Dangerous (?) Sharks

When speaking of sharks the obvious question is: "Are they as dangerous as the stories suggest?" and the answer is: "Not really." It is said that worldwide there are about 100 shark attacks annually, very likely more if all were on record. Many attacks are quite severe; few are lethal; but often they are no worse than dog bites.

Sharks have an excellent sense of smell, hearing and mechanical perception which involves an electrosensory capability associated with a lateral line along the length of the shark connected to ampullae in the head region. These multiple sensory capabilities must have some bearing on when, where, and how sharks might attack but, for reasons not altogether clear, they are more dangerous in some areas than in others. They are also more to be feared under some situations than is normally the case. For my own safety, I abide by current local knowledge. If the residents of a given locale or region are not concerned, that's fine with me. If they worry about shark attacks, I worry too and act accordingly.

Without including the Whale Shark and the Basking Shark, both of which are enormous but only feed by straining the water for plankton, it can be said, as commented above, that the most dangerous sharks are the big ones. The Bull Shark, the Tiger Shark, the Lemon Shark, the Great White of *Jaws* fame, and the Ocean White Tip (not the White Tipped Reef Shark) are often cited when possible danger is discussed (Figs. 15 & 16).

Our fear is associated, of course, with the vicious teeth lining their powerful jaws. Actually the teeth are modified scales and are continuously replaced as needeed; a shark can count on good dentition throughout its life. It so happens that shark's teeth preserve very well and are very common in some fossil beds.

In summarizing the risk of an attack by a shark, one authority has written: "All kinds of things are statistically more dangerous than shark attacks; for example, bee stings, lightning strikes, and, of course, driving a car." Even so, I am providing herewith some tips to avoid an attack if there is a chance that any sharks in your surroundings should be inclined to be aggressive[2]:

- Avoid erratic swimming or splashing. I list this first because Stewart Springer, who researched the shark danger for the Military during World War II, stressed this when we were swimming together in the Florida Keys.

- Stay in groups if possible. A shark is more likely to attack a lone individual. Again, this is advice I got from Stew Springer.

2 When the battleship *U.S.S. Indianapolis* was traveling unescorted to Leyte after having delivered the atom bombs to Tinian, it was torpedoed, sunk in about twelve minutes, and left about 1,100 men in the water subject to shark attacks. While there were reports that sharks killed perhaps as many as 800 men; a documentary, based on inquiries of surviving members of the crew and released by the Discovery Channel in July 2007, states that men died either of exhaustion, exposure to the elements, or drinking the ocean water but not from shark attacks. The sharks mainly fed on the dead or injured; however, this incident is still the worst case known of sharks feeding on humans.

- Don't go in the water if bleeding or menstruating. And you are asking for trouble if you are spear fishing and trailing a string of wounded fish. Remember, sharks have a very acute olfactory sense. We experienced this danger after a member of our research team at Eniwetak Atoll blasted some submerged rocks. Fish trapped in the debris were soon dead and decaying and, when members of our group returned to examine the exposed strata in the rocks, they were greeted by a feeding frenzy of sharks. That bit of research was quickly abandoned!

- Don't go in the water near a sewage outfall or any site where there might be a concentration of organic wastes. Once, when tied alongside the effluent of a tuna cannery, I went overboard to free a line caught in the propeller. I had weighed the risk versus the need to get the job done, and was lucky.

- Avoid areas or conditions in which the visibility is not good. You will be depending on your eyesight which is impaired under water while sharks, depending more on their olfactory and acoustic senses, have an advantage. It seems that being in the water at night is a bit more dangerous than in the daylight.

- There seems to be an increased danger of an attack where rivers are draining into the sea.

- It is well to avoid swimming near a seal or sea lion rookery. Think of the sharks gorging on the mammals coming and going and the risk taken by a human in the area in a typical black wet suit.

- Some SCUBA divers carry a billy club to bash a shark on the nose or across the eyes should it threaten to attack. Some such clubs are rigged with an explosive tip. If a curious shark is just circling and there is no likelihood of an attack, a diver using a billy might just make things worse.

Fig. 15. Jay Moore, my student assistant, poses with spear in hand to show the size of a Bull Shark (tentative identification) caught by a worker at Eniwetak Atoll during our research at the field laboratory there.

Fig. 16. Shark's teeth. Mighty scary to say the least!

- When a vessel is drifting so those on board can enjoy a swim-call, it helps to post a lookout preferably high in the rigging.

- Finally, there is always the hope that a reliable shark repellent might be found or manufactured and marketed.

It's one thing to write as though the shark threat is grossly exaggerated and quite another to read an account of a real tragedy. Thus, on Nov. 3, 2003, while writing that the danger is exaggerated, I was interrupted by a news release of the attack on 13 year-old Bethany Hamilton whose arm was bitten off while surfing in Kauai, the northernmost of the major Hawaiian Islands. Bethany, who was already a top female surfer, has survived and seems anxious to continue surfing once fitted with a prosthesis. It is believed that the attack was by a ~5 m (~16 ft) Tiger Shark. Incidentally, enthusiasts continue to surf at the site of that attack.

In closing this discussion of likely attacks, we should contemplate the possibility that populations of the larger sharks might be declining. First of all, the fisheries for sharks, often primarily for the fins (for shark fin soup) is on such a large-scale in some areas that there seems to be a need for regulation to prevent overfishing. Less of a factor are relatively local efforts in which sharks are being killed in the interest of public safety. Whatever the truth may be as to the present abundance and the future fate of the overall shark population, it is important to recognize that as part of the natural oceanic ecosystem, there are many ways in which these top predators play a very significant role in helping to maintain a normal, balanced environment. Furthermore, if the numbers are greatly reduced, any recovery will be very slow since sharks do not reproduce very rapidly and are slow growers.

Let nature rather than exaggerated fear prevail. In brief, an ocean without sharks is not an ocean.

Chapter XII.
Whales, Dolphins, and other Mammals of the Sea

Sighting a giant whale on the high seas is a thrilling experience but these leviathans are just a sampling of a an extensive group of mammals known as cetaceans that feed, mate, give birth, and even nurse their young at sea (Fig. 1 and the accompanying notes). The abundant dolphins and porpoises are smaller members of this group.

There are two basic kinds of cetaceans: those using baleen for feeding and those with teeth. Baleen consists of whalebone in the form of vertical plates suspended from the upper jaw and having a consistency somewhat like that of fingernails. Being frayed on the sides, the overlapping plates of baleen act like a sieve. Feeding typically involves gulping a large quantity of water or bottom sediment into the lower mouth area; then, with its tongue, the whale pushes the water upward through the baleen filter. Finally, the tongue is used to lick off the food left behind. Thus, these massive mammals are not predators in the usual sense but feed by straining the sea water for plankton or, as in the case of Gray Whales, sieving bottom sediments for other tiny organisms (Fig. 2).

The better known baleens are the Blue, Fin, Humpback, Right, Sei, Gray, Bowhead, Bryde's, and Minke Whales. It is these baleen whales, and the Sperm Whale of the toothed whale group, that supported the great whaling industry of years gone by. They are the whales of songs and fables.

The Blue Whale, growing to 30 m (100 ft) in length, is the largest living animal. They once thrived in Antarctic waters, taking advantage of the abundance of the relatively large plankton crustaceans known as krill.

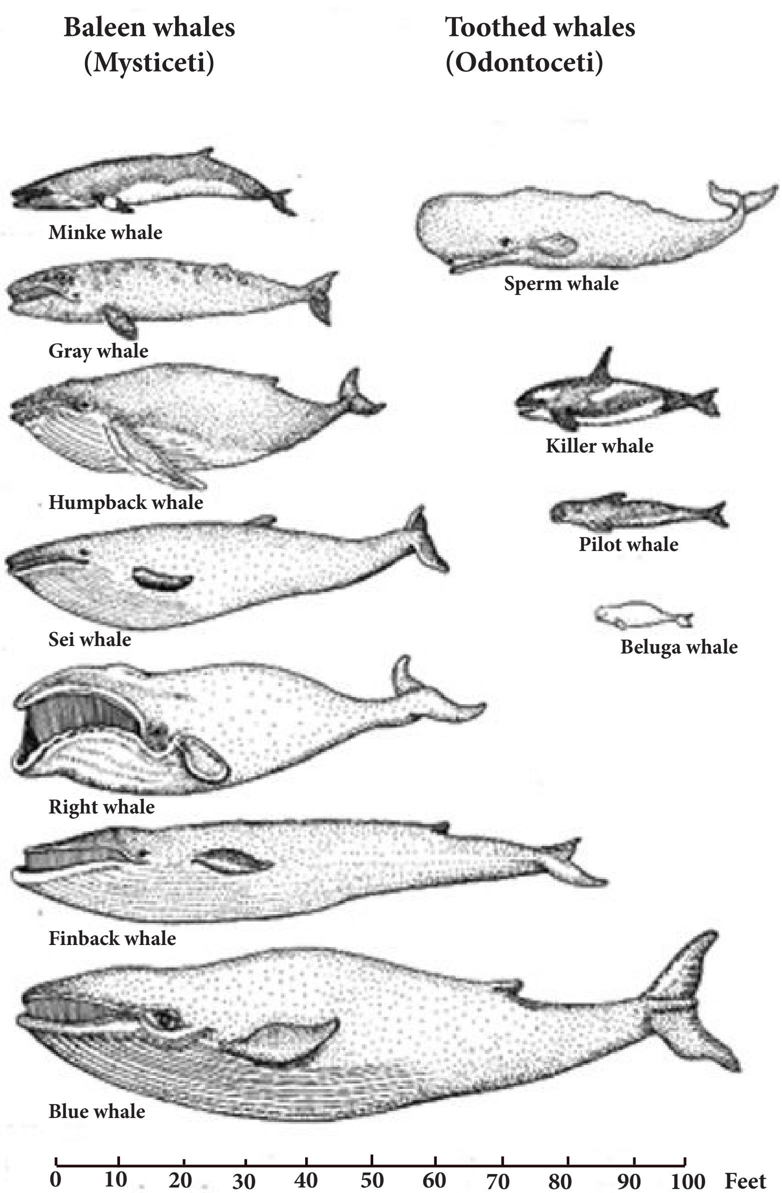


Fig. 1. Great whales you may see. Drawing by Debbie Kennedy.

Notes on the great whales you may see! [1]

Species	Distribution	Avg. Weight	Max. Length	Food
Blue	Worldwide~1	84 tons	30 m (100 ft)	Krill
Fin	Worldwide~1	50 tons	25 m (80 ft)	Krill and other plankton, fish
Humpback	Worldwide~1&2	33 tons	15 m (50 ft)	Krill, fish
Right	Worldwide~3	50 tons	17 m (55 ft)	Copepods and other plank-ton, fish
Sei	Worldwide~1	17 tons	15 m (50 ft)	Copepods and other plank-ton, fish
Gray	North Pacific~2	20 tons	12 m (40 ft)	Benthic invertebrates
Bowhead	Arctic~4	50 tons	18 m (60 ft)	Krill
Bryde's	Worldwide~1, 5	17 tons	15 m (50 ft)	Krill
Minke	Worldwide~1	10 tons	9 m (30 ft)	Krill
Sperm	Worldwide~1,5	35 tons	18 m (60 ft)	Squid, fish

Distribution of the above:
1 = large north-south migrations
2 = large north-south migrations close to the coast
3 = cool and temperate regions
4 = close to the edge of the ice
5 = tropical and warm temperate regions

1 Several of these are represented by different populations or races in separate oceanic areas. Except for the Sperm Whale, all of these are baleen species.

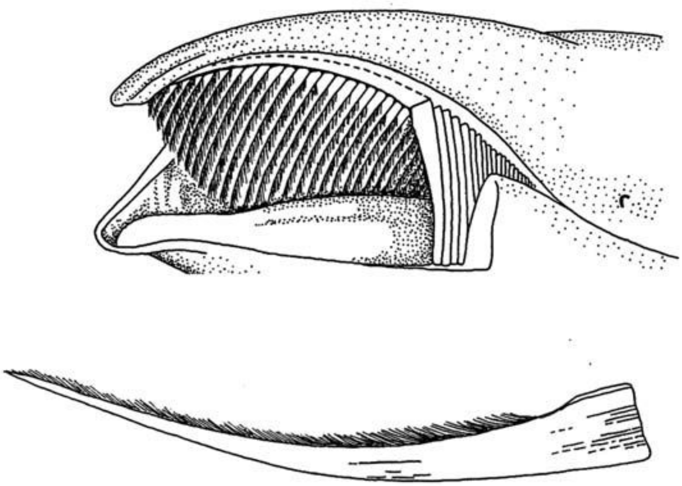


Fig. 2. Baleen: Flesh is removed to reveal the layout of the baleen plates. The lower drawing is a sketch of a single plate. Drawing by Debbie Kennedy.

(See the discussion and illustration of krill in Chapter IX describing plankton.)

No doubt the buoyancy of the water helps explain how the massive size of the Blue Whale is possible. Also, since several of the great whales are larger than the largest dinosaurs, they could well be the hugest animals that ever populated the Planet.

Most of the great whales are highly migratory. Several feed in the summer on plankton-rich waters in the higher latitudes; then return to warm waters for mating and calving. The spring migration of the Gray Whales to their northern feeding grounds and their late fall migration southbound provide good sightings along the West Coast of North America. In addition, the abundance of these Grays in their wintering range off Baja California supports a thriving whale-watching tourist business. Along the East Coast of North America much of the whale watching is focused on migrating Humpbacks (Fig. 3, 4).

Seeing large migrating whales underway, often in small groups and generally moving very slowly, perhaps only 8 km/h (5 mph) or even less, leads one to wonder how they ever reach their distant destinations. They

Fig. 3. Humpback Whale breaching. Source: NOAA.

Fig. 4. The tail flukes of a Humpback Whale. Source: NOAA.

just keep plodding along day and night. Since they may stay submerged for quite some time and surface and blow rather briefly, it takes patience to observe them passing by. They may dive to great depths, perhaps as much as 2,000 m (6500 km) or well over a mile in the case of Sperm Whales searching for deep-sea squid.

Whale watching should be done without disturbing the animals. There are areas along the coast of Baja California where guides taking tourists in small boats encourage them to pet the Gray Whales that may approach out of curiosity and perhaps a bit of friendliness (Fig. 5, 6). In general, however, you should avoid moving any closer than 100 yards (1 km). Patience, approaching slowly, perhaps even drifting and hoping that a curious whale might come close, is the key to good whale watching. Certainly, deliberate harassment of any kind is inexcusable. It's sort of like bird watching where your success depends on letting the birds control the action. Leave it to the whales!

With a pair of binoculars, you can often identify individual whales by differences in their tails and various other distinct markings. Those interested in studying whale behavior commonly use this technique to follow the activities of individuals from year to year. Experienced whale-watchers may also use spout characteristics to identify species when far away. The Sperm Whale, in particular, may be identified by its spout which angles forward from the front of its very large head. The spout of the Right Whale is distinctly V-shaped when seen from the front or from the rear.

Since baleen whales are in essence sieving the water for microscopic food, their feeding methods are uniquely adapted to accomplish this. In some cases, they simply skim the surface with open mouths. Sometimes they lunge laterally or vertically, again with open mouths. Especially impressive, should you happen upon it, is the cooperative bubble feeding carried out by Humpbacks as they encircle quantities of their prey within a curtain of bubbles; then lunge to devour the concentrated supply. As noted above, the Gray Whale commonly scoops mud from the bottom and strains it for bottom fauna.

Historically, the great whales were pursued for oil extracted from the blubber and used for soap, lamp fuel, and lubricant. They were also taken for baleen, commercially referred to as whalebone, which had a variety of uses that took advantage of its combined strength and flexibility. Scrimshaw art was practiced on the large teeth of Sperm Whales

Fig. 5. Gray Whale. Source: NOAA.

Fig. 6. Migration route of the Gray Whale along the West Coast of North America. At 9,000 km (5,600 miles) this is a very long and well known migration. Courtesy of the Oxnard Convention and Visitors Bureau.

(Fig. 7). And, for many, whale meat served as a major source of food. In addition, Sperm Whales provided the very high quality spermacete found in the large frontal region of the head and used in a number of products including candles. This species also regurgitates a dark colored, waxy substance called ambergris used as a scent fixative in perfumes. Occasionally ambergris is found floating on the surface or washed up on the beach.

Whaling had driven many species close to extinction and, as the 1970s drew to a close, it seemed doubtful that commercial whaling could continue as practiced. To counter the extreme decline in numbers, a moratorium on all whaling was put into effect starting in 1986 under an agreement established by the International Whaling Commission (IWC). Certain native groups that had traditionally relied on whales for their livelihood were allowed very limited annual harvests (Fig. 8).

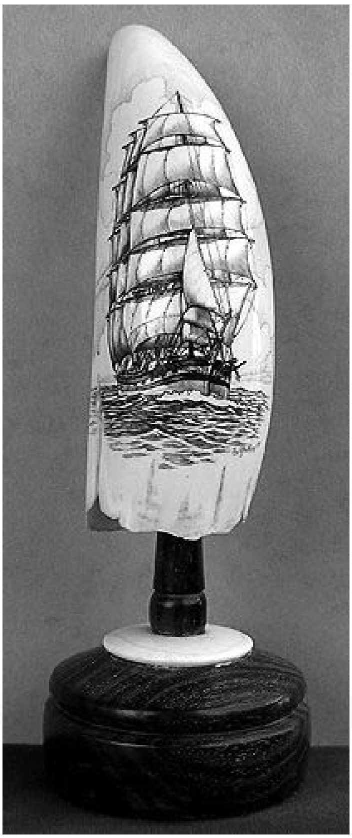


Fig. 7. Scrimshaw: An example of whaler's carvings on Sperm Whale's teeth. Source: Chris Scott, scrimshawcollector.com.

Within the scope of the moratorium, there was also an understanding that a few whales could be taken for scientific studies. Critics have accused Japanese whaling interests of stretching the research provision in order to obtain whale meat for the food market. Others, while not denying that Japan has marketed the meat obtained, agree that the research has been properly planned and has not been excessive (Fig. 9).

Currently, Japan, Norway, and Iceland are continuing to defy the IWC moratorium. Thus Japan reportedly is focusing on Minke, Bryde's and a lesser take of Sperm Whales. Also, these countries plan to take some Humpback and Fin Whales from an area in the Southern Ocean around Antarctica regarded as a sanctuary. As many of

Fig. 8. Whaling off Bequia, where a limited harvest is permitted. Courtesy of Nathalie Ward.

Fig. 9. Yes, they do sell whale meat in Japan. Source: Greenpeace.

the major whale populations have recovered, some countries contend that the IWC should revise the moratorium and openly allow for harvesting under sustainable yield quotas set by proper management. I shudder to think that, after twenty years in which we have learned to think of whales as something quite special, we might be seeing our whale watching pursuits, etc., interrupted by chaser boats hunting their quarry. In the interest of coastal whale watching we could, of course, restrict such whaling to the high seas beyond the Exclusive Economic Zone of 370 km (200 nautical mi), as described in Chapter XIV.

Contrary to the realization that many species have recovered since 1986, we find that the Blue, Right, and Bowhead Whales will need continued protection and that populations of the Western Pacific Gray Whales may be endangered by oil drilling operations off the coast of Russia.

Of special concern is the plight of the Right Whale in the North Atlantic with a surviving population down to the low hundreds. This species is often traveling in the shipping lanes and is inept at getting out of the way of vessels underway. Provisions being made to redirect commercial shipping lanes in the Bay of Fundy to avoid the Right Whale's summer feeding grounds may help considerably. In addition, consideration is being given to the approaches to the Boston area with special attention to the shipping lanes across the Stellwagen Bank Sanctuary and using whale sounds to define areas where ships should slow down. Such undertakings should not only help the Right Whale but whales in general.

Of the various cetaceans, the toothed species are far more diverse than the baleens and many of them occur in greater numbers. This group, of course, includes the Sperm Whale which, had been part of the great whale fisheries of the past. Smaller, toothed species include Belugas (Fig. 10) and Narwhals, the Beaked Whale group, the Pilot Whales, and the Orcas. The toothed cetacean group also encompasses the many dolphins and porpoises.

There are two species of Pilot Whales, both colored black or dark gray with a white blaze running backward from behind the eye and a light

Fig. 10. Beluga Whale in an icy sea.

colored saddle in back of the dorsal fin. The distribution of the two is such that a Pilot Whale may be found in any ocean except the Arctic Sea. Unfortunately, these Whales often become stranded on the beach.

Orcas, alias Killer Whales, are among the most widespread of all cetaceans, being particularly abundant in the higher latitudes (Fig. 11, 12). Groups of Killer Whales may have different feeding styles, some being more aggressive than others. For instance observers tell me that

Fig. 11. Orcas or Killer Whales. Source: NOAA.

Fig. 12. Orca spy-hopping through the ice. Rotating whale spy-hopping suggests that they are checking the entire horizon. Source: NOAA.

along the Northwest Coast of North America the inshore, more local populations, feed almost entirely on fish while the more offshore, transient groups are the real killers that even prey upon large whales. They commonly attack their prey in packs, very much as wolves do; however, in spite of their killer instincts, attacking humans is a rarity.

Some aquarium shows that have typically featured trained dolphins are now turning to *Orcas*. They seem to train about as well as dolphins and I gather they are considered to be a bit more spectacular. Certainly they are larger but, since there is some indication that they do not do well in confinement, animal rights groups have raised objections to showing them. It is not clear, moreover, that, once in captivity, Orcas can readily adapt if returned to the wild.

To test this, it was decided to try to free a very popular Orca named *Keiko* that had starred as *Free Willy* in the movies and had subsequently been kept in large aquaria, first in Mexico, later in optimal tank and show conditions in Newport, Oregon. The first step toward reaclimation was to fly *Keiko* to his original home in Iceland, quite a feat to begin with. Trainers then encouraged him to feed on his own and to venture forth to join other Orcas. Though occasionally he did venture out and meet with others, he preferred to return and hang out at his onshore quarters where he seemed to enjoy the company of humans and was fed on demand. Later *Keiko*, apparently guided by a group he joined temporarily, moved farther along to the coast of Norway. Folks there were looking after him when he finally passed on. *Keiko* never did establish ongoing ties with whales in the wild.

At this point the word *pod* comes to mind as it applies to any group of cetaceans in which the individuals tend to remain together and generally seem to be socially related in some way. Sperm, Pilot, and Killer Whales are especially well known for their pods made up of extended family groupings with some members apparently remaining together for life. In addition to pods, a variety of aggregations of dolphins and porpoises may be encountered. These may be referred to as schools or herds and may involve just a few individuals or may number in the thousands, possibly including a mix of related species.

As we continue to discuss the various toothed species we come to the ocean dolphins; at least 33 species all told. The Bottle-nosed Dolphin, the archetypical member of this group, is quite common along most all temperate and tropical coastal areas (Fig. 13). Its protruding snout and melon-shaped forehead is characteristic of many, but not all, dolphins. Quite similar to the Bottle-nosed Dolphin are the abundant Spotted Dolphins, there being two species, one in the Atlantic and one in the Pacific. These and certain other dolphins tend to congregate over schools of tuna. In the Eastern Pacific purse seiners, acting on the clue that tuna are present, may surround dolphins as well as the targeted fish in a single set of the net. Measures to limit the effect on dolphin populations are discussed in Chapter XIV dealing with the fisheries.

Four species of dolphins are collectively known as river dolphins, although one of these lives in estuarine and coastal marine waters of the

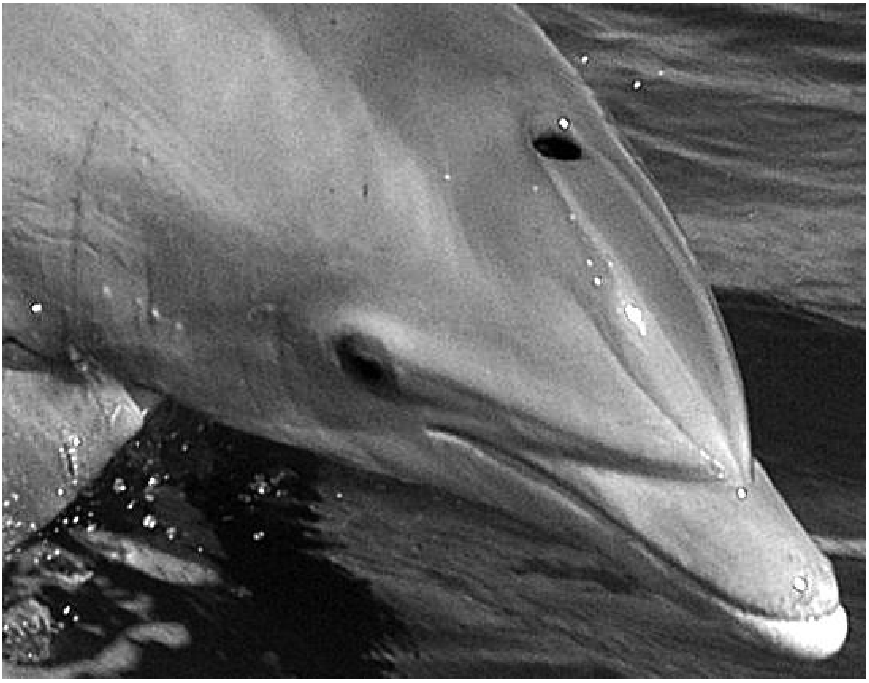


Fig. 13. The Bottlenosed Dolphin. Source: NASA.

temperate region of Eastern South America. All possess distinctive long-narrow jaws and all are very pale, almost white; some with shades of pink. The fact that most of them are freshwater species is, in itself, a significant distinction. The River Dolphin of the Amazon and the Orinoco are probably the best known. One of the species known from the Yangtze

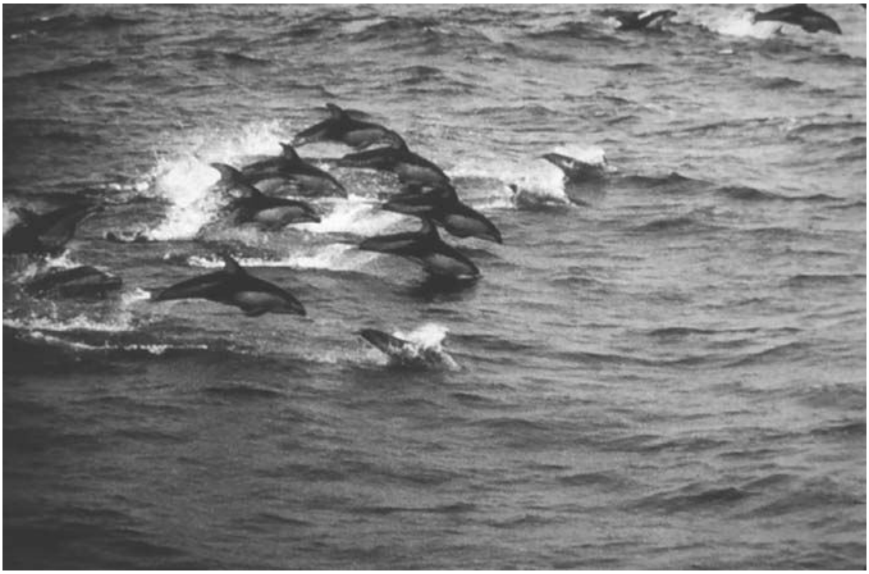


Fig. 14. A pod of dolphins porpoising. Source: NOAA.

River is rare and may have become extinct.

Although the word *porpoise* is commonly used as a synonym or alternative for most all the relatively small cetaceans, biologists limit the term to just a few relatively small species that lack the protruding beak common among the dolphins. The Common or Harbor Porpoise is a very typical member.

Most dolphins and porpoises, with their streamlined bodies and unusually smooth skin, are very good swimmers. Accounts of their swimming speeds range from 15 knots (17 mph) for prolonged periods to over 20 knots (23 mph), at least in short bursts. They are often seen leaping from the surface in graceful, continuing arcs in a pattern known, appropriately, as porpoising (Fig. 14). You have probably observed dolphins playing in this manner as they ride the bow waves of vessels underway, perhaps picking up speed in so doing. I have even read accounts of the smaller cetaceans riding on the bow waves of large baleen whales.

Overall, there are so many different dolphins and porpoises with many looking so much alike in size, shape and color, that you will often need a guide book and a close look if you are to be confident in making an identification. The Audubon Book listed at the end of this chapter serves very well. In addition, the book offers a great deal of information about marine mammals in general.

Now, we come to the most fascinating aspect of cetacean behavior, that which has to do with sound, communication, echolocation, and related intelligence. Most, perhaps all, cetaceans are capable of producing sound. And, by lowering a hydrophone (a rather inexpensive one will do) into the water, the sounds you may hear include long trains of very rapid, high-pitched clicks coming from dolphins. Sound generally emanates from the forehead, and in the dolphins, from the melon-shaped protuberance present in so many species. Some of the sounds produced, including whistles, are the signature calls of individuals. Thus individual Sperm Whales emit distinctive sound patterns called codas. Among the Killer Whales there are dialects associated with family groupings. Humpbacks are noted for their singing for hours at a time. Blue and Fin Whales are noted for the volume of the sound produced that is beyond the range of hearing in humans. With suitable equipment, their sound can be picked up 3,200 km (2000 mi) away.

Sound may be used in echolocation, which among other things is useful in finding food (Fig. 15). The research on the further use of sound is very fascinating. Much of it is focused on the Bottle-nosed Dolphin, indicating that the communication skills of cetaceans are coupled with a high level of intelligence. There is reason to believe that some, possibly all, members of the whale, dolphin and porpoise groups, are every bit as smart as our pet canines and even the higher apes. They are truly remarkable animals, many being characterized as curious, gentle, friendly,

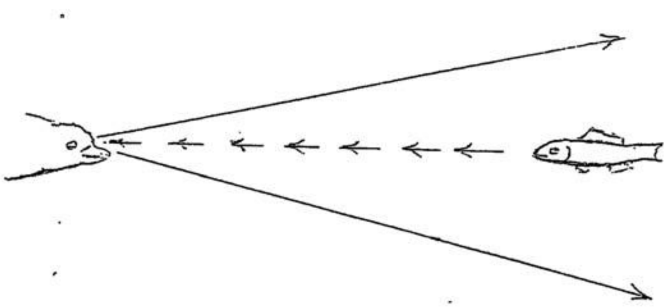


Fig. 15. Echolocation. Sound produced by the dolphin is reflected off the fish and helps the dolphin to find it.

and easily trained.

The potential for training is exhibited over and over in popular aquarium shows. Not as well known, though even more impressive, is the practice of using dolphins to carry messages underwater and to assist divers. I am told that this capability was involved as a couple of dolphins were transported to Iraq to help in the search for mines during the invasion of 2003. They are so keen that they can point the way to mines without exploding them.

On the down side is the concern that cetaceans, and marine life in general, may be disoriented or may otherwise suffer physiologically from human-generated sounds. There have been numerous reports that sonar as used in naval exercises has caused the strandings of disabled cetaceans.[1] There is also a concern over other uses of sound such as those employed in locating oil and gas deposits. This overall problem is being addressed one step at a time. Though the U.S. Navy contends it should be exempt from various aspects of the Marine Mammal Protection Act that limit the use of underwater sound, it has accepted certain court orders limiting this use.

Inevitably, using underwater sound, whether for military purposes, for seismic sounding in oil exploration, for scientific research, and for other purposes, will continue to raise concerns as to possible adverse impacts on the life in the sea.

While commenting along these lines, I am reminded that during World War II the military, for good reason, became very interested in the transmission of sound in water where it may travel as much as four times the speed in air. Speed and direction are greatly modified by the temperature and related density of the water. Taking advantage of this, it is possible for submarines to hide under density layers in the ocean. One of my colleagues, Dean Bumpus, spent World War II on assignment from the Woods Hole Oceanographic Institution teaching Navy personnel to take advantage of these properties (Fig. 16). He told me that submariners were his most attentive students.

Actually many questions related to defense led to a sudden growth of oceanographic research during World War II . Suddenly there was a need to know more about all aspects of noise below the surface, including

1 Not all observed strandings have been linked to man-induced underwater sounds. Some disorientation has been associated with disease; some remains a mystery.

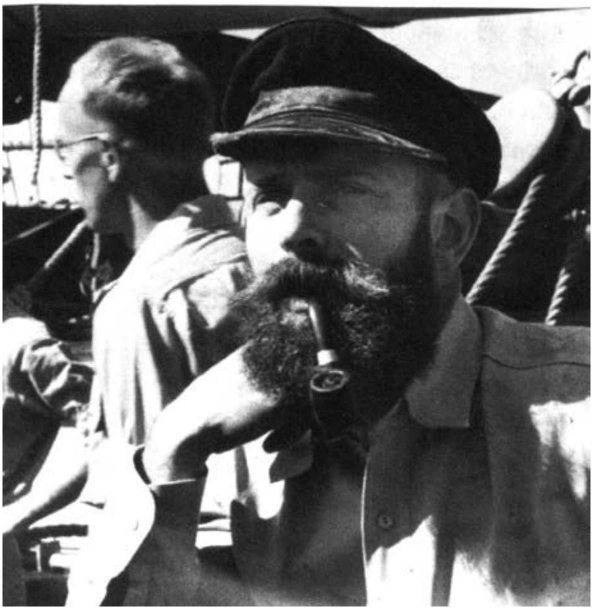


Fig. 16. Dean Bumpus. Photo courtesy of the Woods Hole Oceanographic Institution.

sounds produced by various living organisms and sounds reflected off migrating zooplankton. Of course, noises produced by whales and fishes also attracted considerable attention. Accordingly, to address this research and other defense questions related to ocean conditions, heavy demands were placed on the larger oceanographic institutions in the United States. This was the beginning of greatly increased funding for ocean-related studies. Furthermore, as such support continued after the War, with more diverse aspects of ocean research being included, many scientists who had been working on the defense programs, some of whom had no previous associations with oceanography, went on to become career oceanographers. Our numbers had grown and, as many of us with these interests returned to academic life, graduate programs in oceanography were established in several universities. I think of this expanded group involved during World War II and continuing thereafter as the first generation of modern oceanographers.

In contrast to the cetaceans, i.e. the whales, dolphins and porpoises, none of which come ashore except when they become stranded and perhaps are sick, you may see various pinnipeds, (e.g. seals, sea lions, and

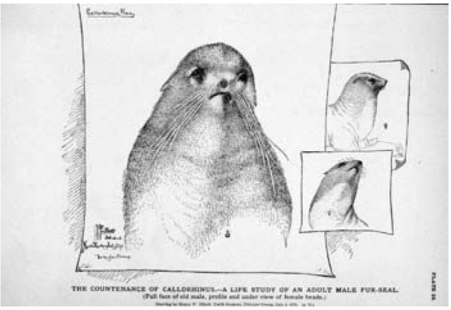


Fig. 17. Sketches of Fur Seal, adult male and smaller adult females. Source: NOAA.

walruses) if your travels take you near their haul-out areas on rocky islands and coasts. These marine mammals depend on coming ashore for mating, giving birth, nursing, often just for loafing. Two large and somewhat different groups exist, one of which includes the fur seals and sea lions and totals at least 15 species (Fig. 17, 18). These are the walkers since, with their long flippers, they can walk on shore, though quite clumsy in so doing. They are also distinguished in having external ear flaps.

Of this group, the California Sea Lion, is especially familiar to the public as it is often kept in captivity, trained, and simply referred to as a seal. In

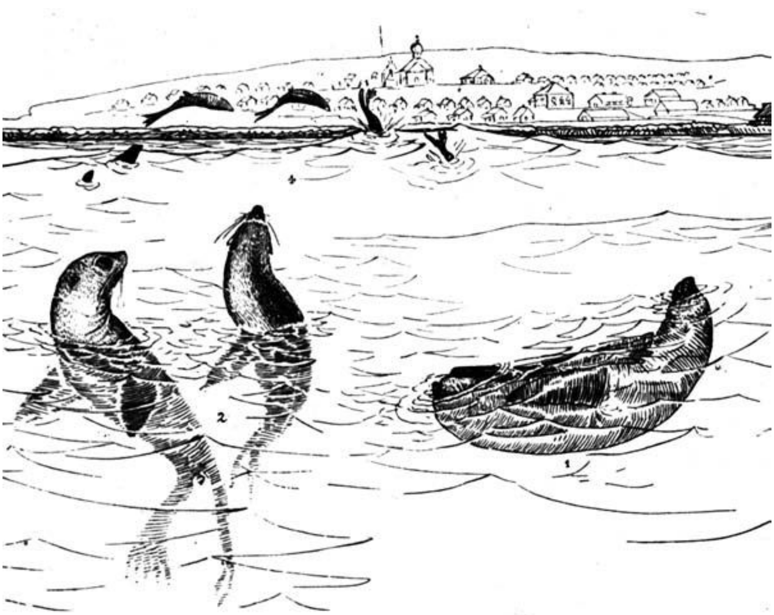


Fig. 18. Two Fur Seals are rising to breathe and survey the surroundings; another is sleeping with its snout just breaking the surface. Dolphins are seen porpoising in the background. Source: NOAA.

coastal areas where they are abundant, you will hear their noisy barking. As they seek food and feed in areas where salmon become concentrated, fishers consider them to be quite a problem.

There are 18 species in another group known as the true seals. They are earless and have smaller flippers. They sort of wriggle on their bellies to move when out of the water. Actually, they do rather well in climbing aboard ice flows. They are especially abundant in the Arctic and Antarctic. One species, the Crabeater Seal, is probably the most abundant of all of the various pinnepeds. There may be as many as 30 million in the Antarctic where they thrive on krill by straining these planktonic species through their interlocking upper and lower teeth. The gray seal of the North Atlantic shore is another predator that has become of concern lately because of its heavy toll on the ground fishes of the intensive commercial fisheries.

Further members of the true seal group include the Leopard Seal, perhaps the foremost predator among all the pinnipeds. The Leopard Seal is also common in the Antarctic where it may capture penguins just as they are sliding off the ice.

The Harp Seal, found on ice flocs in the high latitudes of the North Atlantic, is yet another very abundant true seal. They are hunted simply by clubbing enormous numbers on the ice flows. There is considerable opposition to this cruel hunting practice which includes taking the pups called *whitecoats*, wanted for their long, wooly, white, lunago coats. With the recent warming and loss of favorable ice flows, there has been a great loss of pups from drowning.

A rather familiar member of the true seal group is the Harbor Seal. It is five to six feet in length, rather small as seals go, and has a distinctive spotted coat. Harbor Seals are fairly abundant in nearshore, coastal habitats north of the Equator in the Pacific and the Atlantic Oceans.

Due to various treaties and agreements to avoid the excessive hunting of the past, many seal and sea lion populations are now quite robust. An exception is the Stellar Sea Lion of the North Pacific (Fig. 19). With a decline of 80% in the population in the Western Aleutians, they have been listed as an endangered group. This is an unusually troublesome case as the cause of decline continues to be rather mysterious. Populations along the West Coast of North America are doing better.

Courting, mating, and related territorial claims are generally rather elaborate in these marine mammals as they haul out on shore for mating

Fig. 19. Stellar Sea Lions. This species has undergone heavy mortalities since 1950, the causes of which are not well understood. Source: NOAA.

Fig. 20. A male Elephant Seal. An alpha bull will weigh as much as 800 pounds and will mate with as many as 50 cows, all considerably smaller. These seals migrate very long distances. Source: NOAA.

where, in many cases, the bulls establish their separate harems. The largest seals of all, the Elephant Seals, of the earless group, are a prime example with a great size difference between males and female (Fig. 20). The fight of a large bull to establish and defend his territory with a surrounding of cows is especially bloody. The males that may dominate in the future have to be satisfied with hanging out around the periphery of the rookeries awaiting their turn or, more likely, the day when one of them, through brute force, ascends to a dominant role.

All these pinnipeds are fish eaters, so much so that conservation groups are sometimes at odds with those who, because of the heavy predation on fisheries populations, would like to control their abundance.

In addition to the occurrence of these mammals on haul-out areas where they are most readily seen, you may encounter them at sea, perhaps resting in groups and sometimes in their wanderings to good feeding areas. Elephant seals, in particular, may be seen migrating far out at sea.

Fig. 21. Walrus. Source: NOAA.

Walruses, with their large protruding tusks, have somewhat the same habits as the various seals (Fig. 21). They are pretty well restricted to

Fig. 22. Sea Otter. Drawing by Debbie Kennedy.

Fig. 23. Polar bear. The bear that goes to the sea. Cubs are staying with the adult, which has been sedated to take measurements. These inhabitants of the Arctic are very strong swimmers that prey heavily on seals and fish. Source: NOAA.

northern regions. Close to the coast and widespread in much of the Pacific, especially where there are kelp beds, you may see the enchanting Sea Otters (Fig. 22). They are often floating on their backs, some of them holding their pups on their bellies. Otters have fore and hind legs suitable for coming ashore. Their association with kelp is very important since they feed on sea urchins which, if too abundant, destroy the kelp beds that provide nursery habitats and cover for many marine species. (Kelp is illustrated and mentioned further in Chapter XIX in describing vegetation that washes up on the beach). A smaller species, the Marine Otter, is found along the West Coast of South America.

Polar bears spend much of their lives swimming or on sea ice flows from which they hunt for seals and fish (Fig. 23). Because of the retreat of the sea ice due to global warming, there is considerable concern for the survival of this marine representative of the diverse bear group.

For identification and other information on the animals covered in this chapter, see:

National Audubon Society Guide to Marine Mammals of the World by Reeves, R. Randall, Brent S. Stewart, Phillip J. Clapham, and James A. Powell, illustrated by Pieter A, Folkens., 2003. Alfred A. Knopf, New York.

Whales, Dolphins, and Other Mammals of the World by Shirihai, Hadaram and Brett Jarett, 2006. Princeton University Press, Princeton, N.J.

Chapter XIII.
Turtles of the High Seas

Though sea turtles are generally regarded as either endangered or threatened, you may occasionally see them in their coastal breeding areas and even on the high seas. Widely distributed throughout tropical and semi-tropical seas are the Green, Hawksbill, Loggerhead, Leatherback and two species of the smaller Ridley Turtles (Fig. 1, 2). A species known as Flatbacks nests only in the vicinity of Australia.

Due to their breeding habits, which are rather similar for all species, mortality is quite high. At night, a female turtle will lumber up the beach to a site above high water; turn to face the water; dig a hole with a hind flipper; lay (drop may be more descriptive) her leathery eggs in the hole; cover them with sand; then crawl back to the sea. Dogs, feral pigs, and wild predators find turtle nests rather readily and dig into the covering sand to feast at will. Though conservation regulations commonly forbid humans from disturbing the nests, poachers sometimes collect eggs, and may even market them.

If you are near a nesting beach during the height of the breeding activity, you might try walking along the shore at night. You may witness the scene I have just described.

Incubation may take approximately two months. Upon emerging, the hatchlings scurry on their bellies with little legs paddling on the sand as they make a bee-line into the surf, all the while being heavily preyed upon by Ghost Crabs and various carnivores including gulls. Once in the water, the newly hatched are attacked by predatory fishes and crabs.

A very simple hatchery practice involves digging up eggs and reburying them at sites where barriers are maintained to keep out

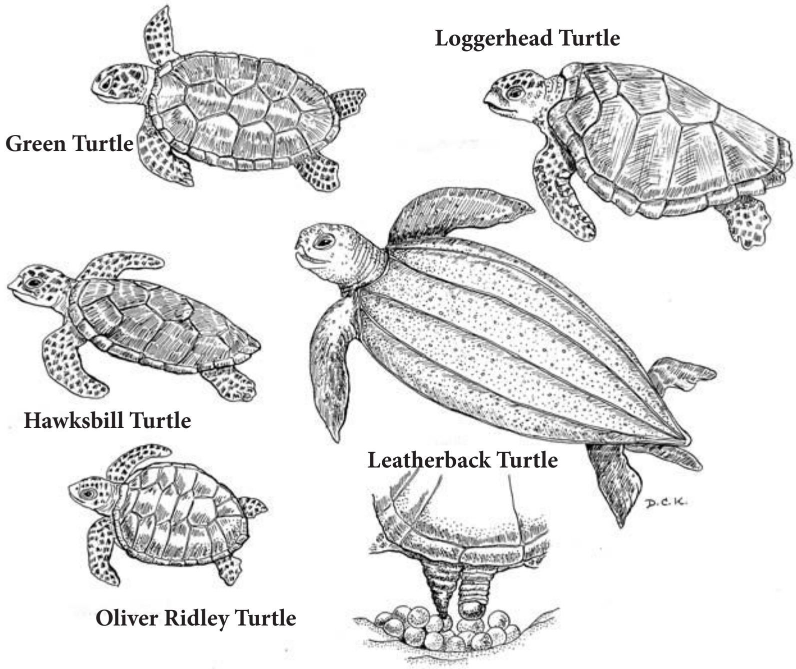


Fig. 1. Turtles of the high seas. One figure shows a turtle depositing eggs in the sand. Drawing by Debbie Kennedy.

predators. This works quite well provided the temperature in a new nest is the same as that at the original deposition site.

As they grow, many sea turtles migrate great distances. Leatherbacks may wander to cooler waters, some even reaching Labrador and Chile. Loggerheads hatched on North American shores may follow the great North Atlantic gyre, wandering to Europe then returning. Also, Loggerheads hatched in Southern Japan are known to migrate across the Pacific to Baja California before returning to Japan.

The diet of sea turtles varies. Green Turtles are known to eat bottom vegetation, Hawksbills may feed primarily on sponges and mollusks, and Loggerheads and Ridleys may feed on crabs, mollusks, and other invertebrates. Leatherbacks, the largest of the sea turtles, sometimes weighing well over 700 lbs (300 kg) have an odd craving for jellyfish. It's

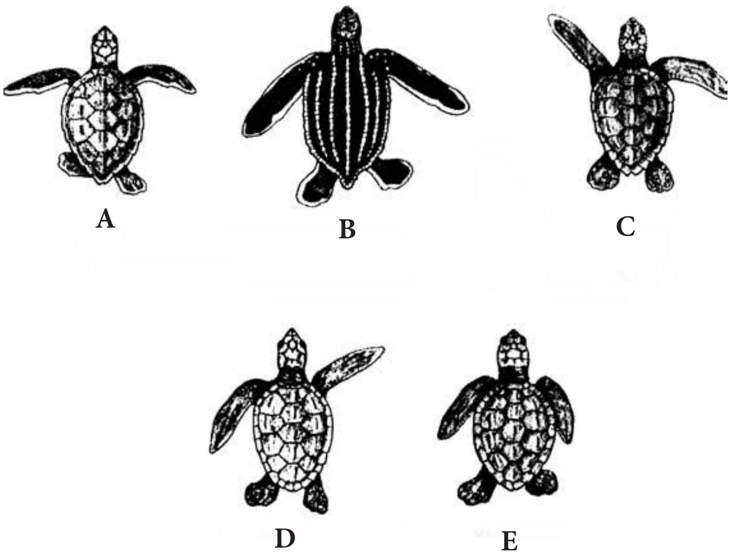


Fig. 2. Sketches of hatchlings of five sea turtle species. A. Green, B. Leatherback, C. Loggerhead, D. Hawksbill, E. Kemp's Ridley. Source: Sea Turtles of the Georgia Coast.

hard to think of a creature so massive thriving on something as watery as a jellyfish, but this reminds us that there is more substance to a jellyfish than is commonly realized.

After their early growth, turtles might suffer minimal losses were it not for being caught in shrimp and fish trawls, on longline hooks, or in gill nets. Then the turtles drown as the gear holds them beneath the surface. Some nations, including the United States, stipulate that fishers attach turtle escape devices (TEDS) to their trawls. Though highly recommended as a conservation measure, the effectiveness of TEDS is somewhat offset when turtles are repeatedly netted and suffer accordingly. Also, there is concern that the openings of some of the TEDS are not sufficient to allow the larger turtles to escape.

When it comes time to reproduce, female turtles typically return to deposit eggs in or very close to the beach sites where they were hatched. In some cases, those Loggerheads that have crossed the Atlantic or the entire Pacific cross the ocean again to return to their home sites. Obviously, such returns to the home beach involve amazing navigational capabilities. Recent evidence suggests that they use an internal compass sensitive to the Earth's magnetic field, evidently similar to the mechanism believed to be used by many migrating bird species.

Though harvesting sea turtles is banned by many countries, there are areas where it is allowed and the meat, which reportedly tastes like veal, is highly prized. In addition to turtle meat, the luxurious shell of the Hawksbill, used for jewelry, combs, and other ornaments, is a notable turtle product. Many countries have placed a ban on the international import or export of turtles and turtle products but, unfortunately, they are subject to a considerable black market.

Sea snakes, some 70 species all told, found in the warm waters of the Pacific and Indian Oceans, are the only other reptiles you might encounter on the open ocean. You can readily identify them because their tails are flattened for swimming. Their bite is highly toxic; however, though they are curious and may come quite close to a diver or swimmer, they don't attack. Their mouths are too small to be able to bite effectively if they were to attack, yet there are cases where fishers have died as the result of being bitten while disentangling sea snakes from their nets.

Chapter XIV.
Fisheries and the Law of the Sea[1]

The major fisheries of the world are in regions of relatively high plankton productivity. Accordingly, using a map of productivity (Fig. 1), you can locate several of the major fisheries areas. You will see an arc of high productivity across the North Atlantic, which includes the Grand Banks that have been the focus of one of the world's great fishing grounds. Similarly, there is a region of high productivity and good harvests in the North Pacific. Upwelling locations such as off Peru, seasonally off the West Coast of North America, and in regions of divergence both along the Equator and near the Antarctic Continent,[2] are also highly productive and may support major fisheries. With many of these and other productive areas being over the continental shelf and other shallow areas, we find that most of the large-scale ocean fisheries are concentrated in about 15% of the world's oceans (Fig. 2).

As you encounter various fishing vessels in your travels, you may become aware of these more productive areas. You may see trawlers (Fig. 3) dragging for bottom-dwelling species, perhaps for Cod, Haddock, Pollock, Hake, Turbot, Redfish, and various flatfishes if you are in the

1 Your observations on the surface tell you very little about the abundance and variety of the fishes in the ocean. However, you can learn a great deal from observing the fishing activities you encounter in your travels.

2 Due to the moratorium on whale harvests established by the International Whaling Commission in 1986, the Southern Ocean close to Antarctica has not been a major fisheries area in recent years; however, from proposals being considered by the IWC, it is possible that whaling may be revived, presumably under a sustainable yield plan. (See the relevant comments including the projected whaling by Japan, in Chapter XII.)

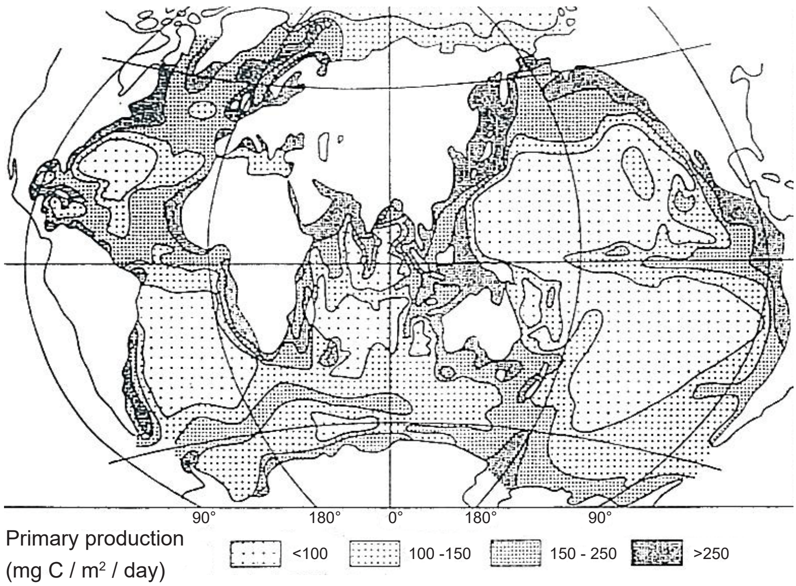


Fig. 1. Primary phytoplankton productivity in the world's oceans. Source: Redrawn from Koblents-Mishke, 1970 in publication of the National Academy of Sciences.

North Atlantic; perhaps for Pollock, Rockfishes, Snapper, Hake, Ocean Perch, Sablefish and various species of soles or flatfishes, if you are in the North Pacific. Anywhere off the coasts of the world you may see trawlers rigged to drag the bottom for shrimp (Fig. 4). Vessels dragging for Sea Scallops will be using a rig that is more like a dredge than a trawl. Finally, some of the trawlers may have their funnel-shaped nets rigged to tow at mid-depths to catch such pelagic species as Herring, Mackerel, also Hake when they move up to mid-depths. A rather unique technique, sometimes used for trawling at mid-depth, involves boats working in pairs towing a net between them.

Perhaps you will encounter boats tending drifting gill nets (Fig. 5). Unfortunately such nets, when deployed over great distances, drown large numbers of seabirds, dolphins, other mammals, and turtles that get tangled in the netting. Similar drownings may be caused by the longliners that you may encounter. The lines they deploy are rigged with baited hooks for such target species as tuna, swordfish, and sometimes for sharks (Fig. 6). Lines on the order of 60 km (40 mi) have been used though increasingly international agreements and conservation measures are

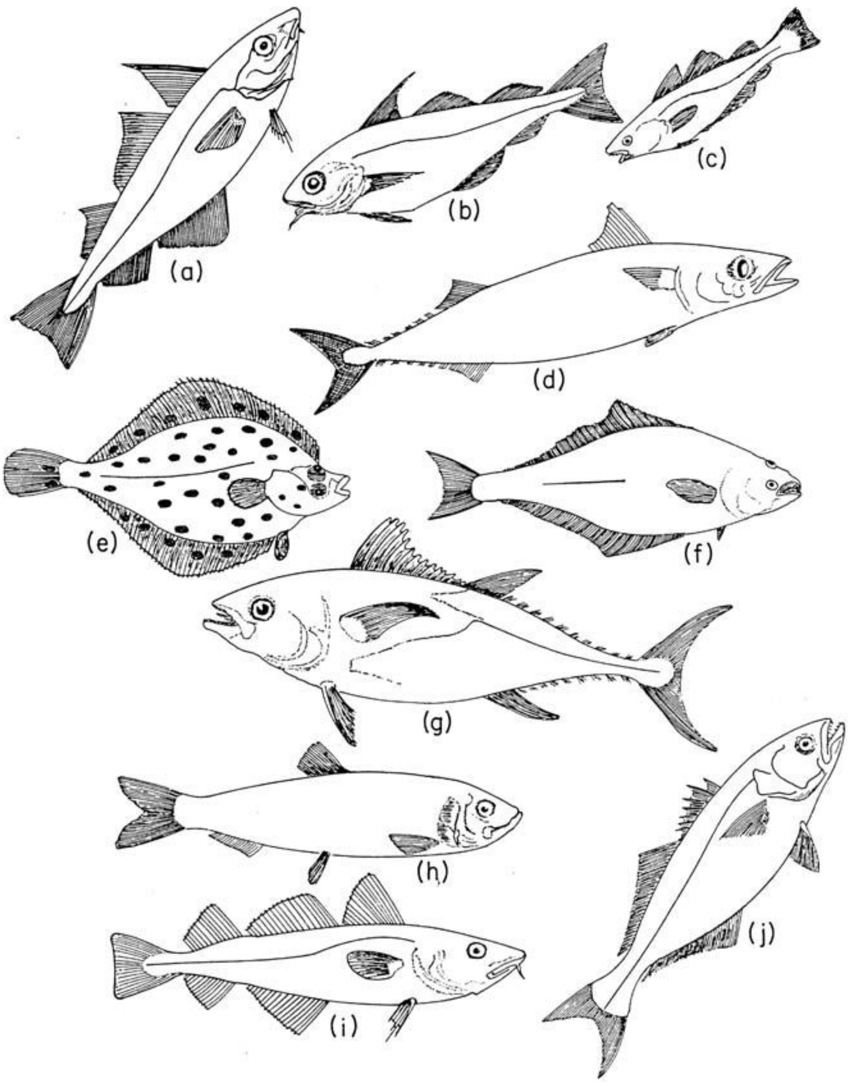


Fig. 2. Common commercial fishes: (a) Pollock, (b) Haddock, (c) Whiting, (d) Mackerel, (e) Plaice, (f) Halibut, (g) Tuna, (h) Herring, (i) Cod, (j) Bluefish. Redrawn, not to scale, from Animals, *a pictorial archive.*

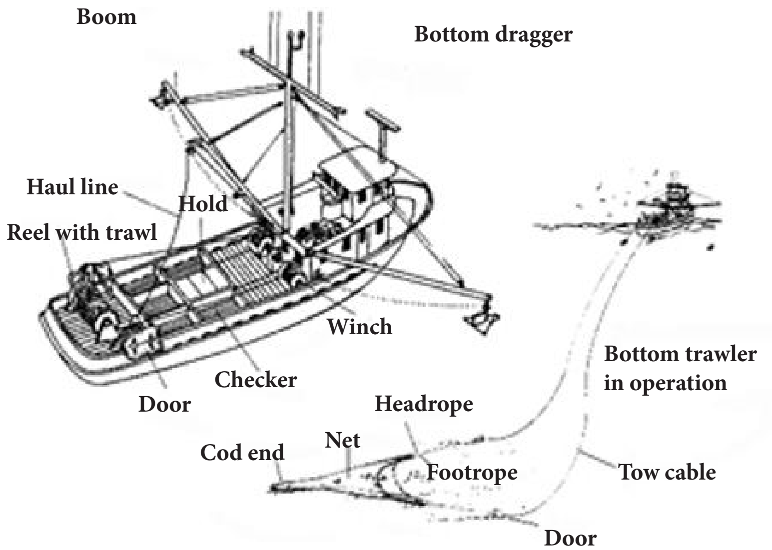


Fig. 3. Offshore fishing boat rigged for bottom trawling; often referred to as a dragger. Source: Oregon Sea Grant.

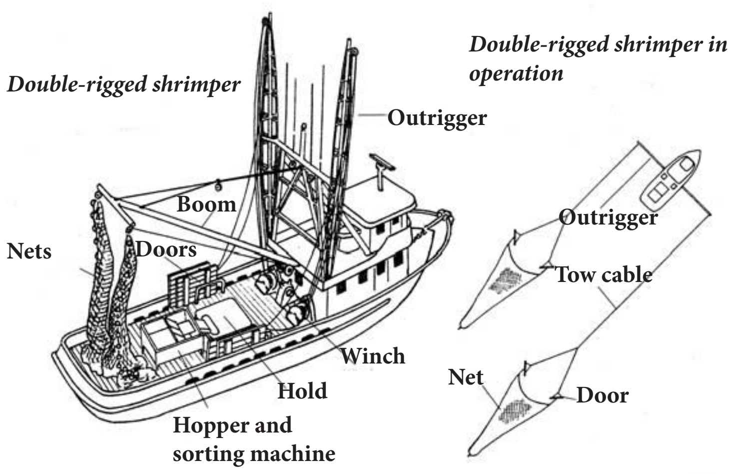


Fig. 4. Shrimp trawler. Source: Oregon Sea Grant.

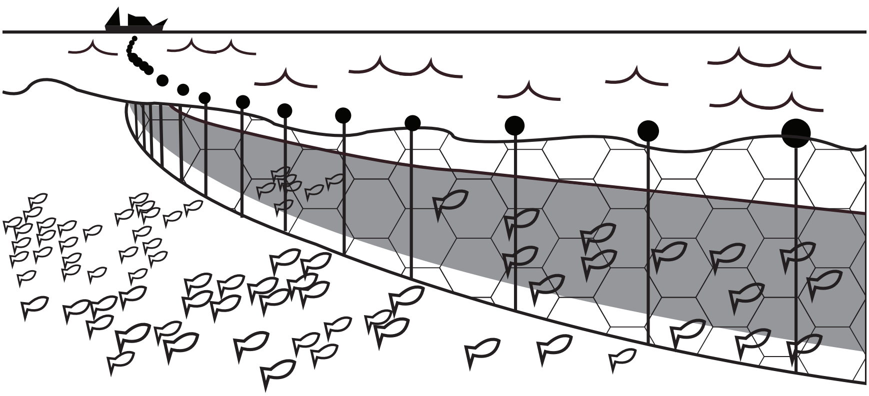


Fig. 5. Drifting gill net. Adapted from Principles of Oceanography by R.A. Davis.

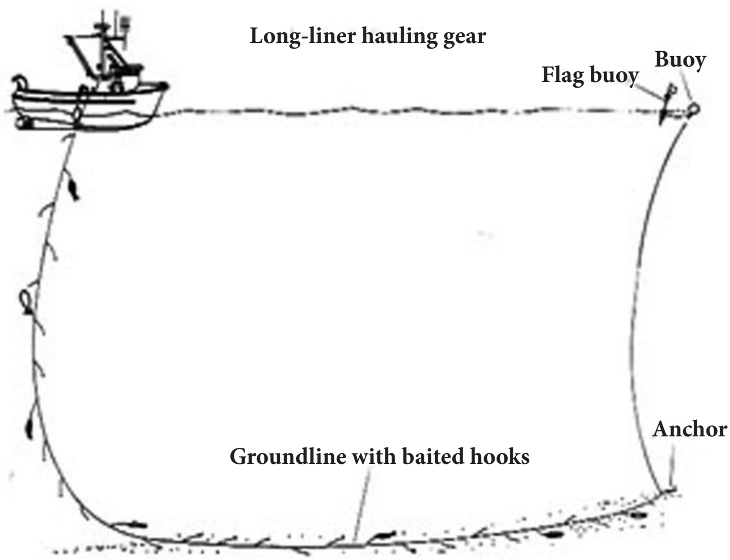


Fig. 6. Long line. Source: Oregon Sea Grant.

limiting the length of the sets permitted both for gillnets and long lines.

Gill netting and longlining remind me that any vessel fishing far from its home port may be caught in very adverse weather. The danger is compounded if, after success on the fishing grounds, the crew is determined to return to the home port to sell the catch no matter how great the distance involved. It was the crew's determination to return from the distant North Atlantic to Gloucester, Massachusetts with its banner longline catch of Swordfish that resulted in the fate of the *Andrea Gail*. The sinking with all hands has been vividly described in the widely read book and movie titled *The Perfect Storm*. Of course, that one storm and the loss of life is but a sample of similar tragedies at sea, not to mention the close encounters in which vessels and crew have survived though heavily battered.

The large purse seiners you may encounter in the tropics and subtropics are usually after tuna. Some ships carry helicopters to help find schools of fish. Anyone with an eye for fine ships will appreciate the sleek lines of a modern tuna clipper (Fig. 7). A number of tuna species are taken by these purse seiners but the most spectacular, namely the fully grown Bluefin Tunas, may be a bit large for ordinary seining operations. These adults may be taken on long lines or as trophy species often in tournaments. These pelagic Olympians can travel thousands of miles and can accelerate up to 45 knots (~ 50 mph).

Smaller purse seiners may be seen fishing for a variety of other fishes, perhaps Herring, Anchovies, Sardines, or Menhaden. Off the Northwest Coast of North America small purse seiners may be used in the salmon fishery, though an important alternative for catching salmonids is to troll with baited hooks (Fig. 8, 9).

The various salmonid species caught at sea have put on weight and matured in the productive coastal and offshore waters. They will enter the coastal estuaries after a few years at sea and, leaping the rapids as they go, they swim up to their home streams to spawn. Thus, the wild stocks return to the very stream beds where they had hatched. The species along the Pacific Coast of North America die after spawning. The closely related Steelhead Trout may return to the sea and repeat the spawning run later. Also, such repeated spawning is characteristic of the salmon of the North Atlantic.

Though hatcheries, also enclosures used for farming salmon, are either well inshore or far upstream and are not part of your observations on the

Fig. 7. A modern tuna clipper. A pad just after the mast is for a helicopter used to spot schools of tuna. Source: Fisheries News International.

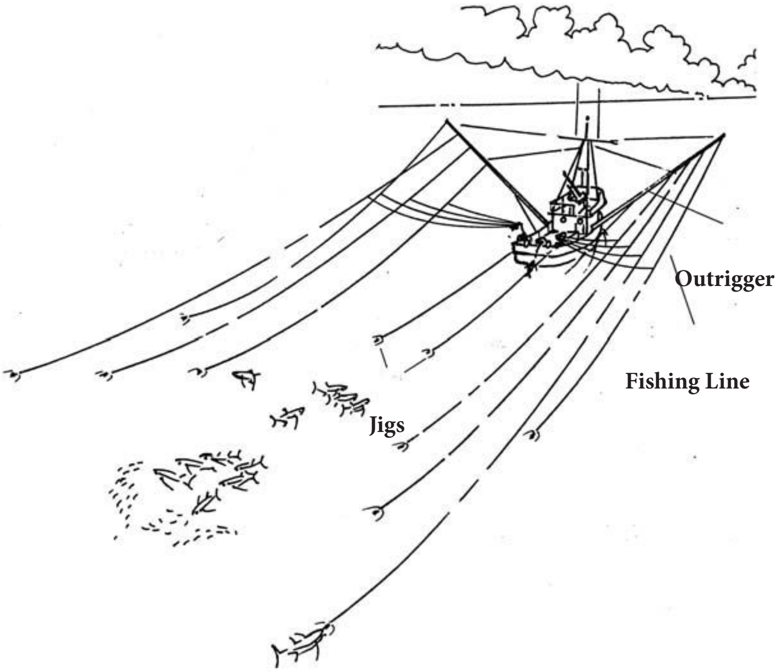


Fig. 8. Trolling rigs with baited hooks as commonly used for salmon fishing off the West Coast of North America. Source: Oregon Sea Grant.

Fig. 9. Fishing boats, mostly rigged for trolling, docked in Crescent City, California.

high seas, a brief description of these operations is needed to complete the story of these fisheries. Hatcheries for the various salmon species take adults as they are en route upstream to spawn. At the hatchery, the fish are stripped of their eggs and sperm and the eggs are fertilized. Then they are reared to the fingerling stage in tanks. Finally, the fingerlings are released and allowed to make their way out to sea. As hatchery fish mature they enter the offshore commercial, fishery and later, as they return to the estuaries and upriver streams, they compete with the wild stocks. Since, on the spawning grounds, wild fish do not do well under the stress of such competition, the role of hatcheries is somewhat questionable.

The farming method for raising salmon involves enclosures, or net pens, which are usually located in protected coastal waters. The fish are artificially fed, and, once they have grown sufficiently, are taken directly to market. Such mariculture has prospered where the various stress problems relating to rearing in pens have been adequately addressed. As food, wild salmon are generally preferred over hatchery or farm-produced fish.

Purse seining, whether by the larger clippers for tuna or for other fishes where smaller boats might be used, is fun to watch should you have the opportunity (Fig. 10, 11). With every means possible, such as high lookouts, spotter aircraft, etc., the fishers locate and zoom in on large schools. Then with great skill, they deploy a skiff from which they surround the schools with a long seine. Once the bottom of the seine is pursed, there is no escape and the net, hopefully heavy with a good catch, is hauled aboard. Large tuna clippers may catch considerably more than

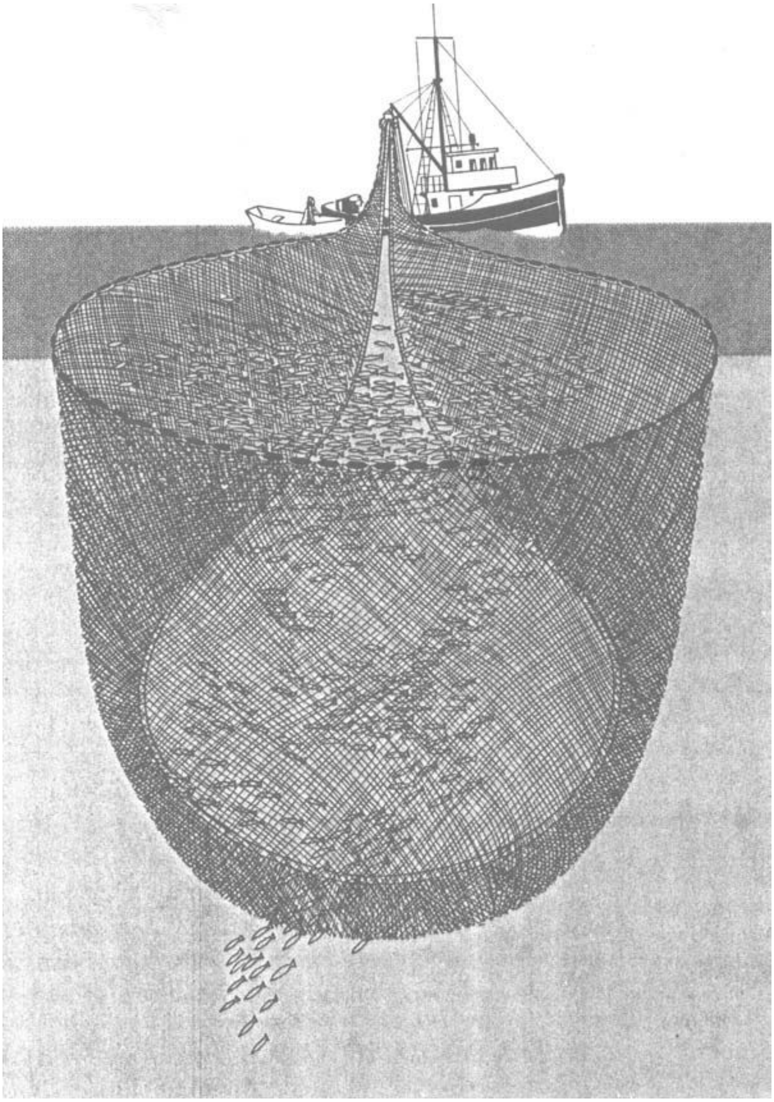


Fig. 10. Small purse seiner with seine deployed and ready to be "pursed." Source: Oregon Sea Grant.

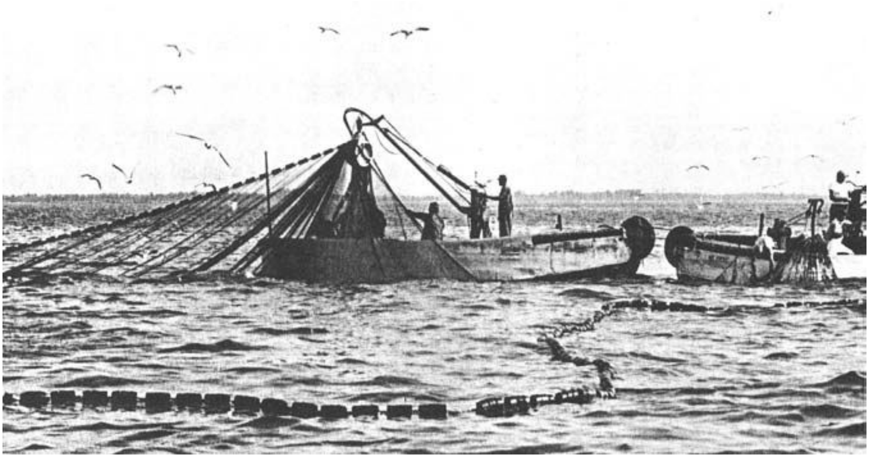


Fig. 11. Hauling in a school of Menhaden with a purse seine. Source: National Marine Fisheries Service.

100 tons in one such set.

Traps of various designs may be used for catches of fin fish. But more familiar are the pots, as they are commonly called, used primarily in fishing for various species of crabs and lobsters (Fig. 13). These may be set separately or in line and, if you are in an area where heavy fishing is going on, the surface of the sea may be crowded with buoys attached to the hauling lines. What I think of as true Lobsters, (i.e. those with the large crusher claws, are caught using pots along and off the coasts of the North Atlantic. Spiny Lobsters, lacking the large claws, are widely distributed and caught in trap fisheries throughout the subtropics and tropics.

Blue Crabs are taken in pots in embayments and offshore along the East Coast of North America and Dungeness Crabs are harvested off the Pacific coast. If you are venturing in the high latitudes, you may see vessels running lines of large traps in the fishery for King Crabs. Three species are taken commercially. Due to the dangerous seas, icing encountered in the high latitudes, and the large traps being handled, harvesting King Crabs is unquestionably the most dangerous of all commercial fishing operations.

As you come upon the various commercial operations, you will realize that the fishers have a remarkable ability to judge where the best catches are to be found (Fig. 14). They are also aware of the movements of the various species and they shift their efforts accordingly, sometimes

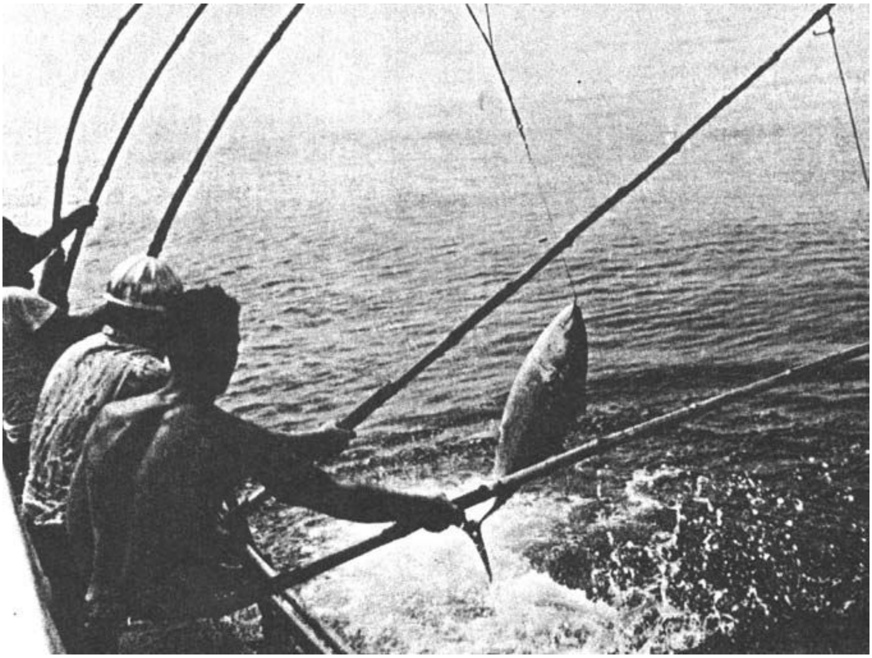


Fig. 12. Pole fishing for tuna–an old method still practiced. Note: Men and poles are lined up in threes along the deck to boat Yellowfin Tuna. Source: National Marine Fisheries Service.

seasonally. The clues they use include water temperature, the color of the sea, foam lines, the winds, birds feeding on small fish chased to the surface by predators, and much more. Of course, they also rely on their charts and their sophisticated electronic instruments, often using underwater sonar to detect concentrations of fish. Their insights are largely based on experience along with some knowledge of the habits of the fish to be harvested.

Fishers from their insights, and fisheries scientists from their research, have much to share. You might say that fishers often have an uncanny sense as to where the fish are and, increasingly, fisheries scientists and oceanographers are learning why the fish are there and how abundant they are. (Or, unfortunately in these days of very heavy fishing pressures, why they are often scarce where they used to be taken in great numbers.)

Over the years, in trying to establish guidelines for management, fisheries scientists attempted to calculate the maximum sustainable yield, the so-called MSY for separate targeted species. Since such calculations

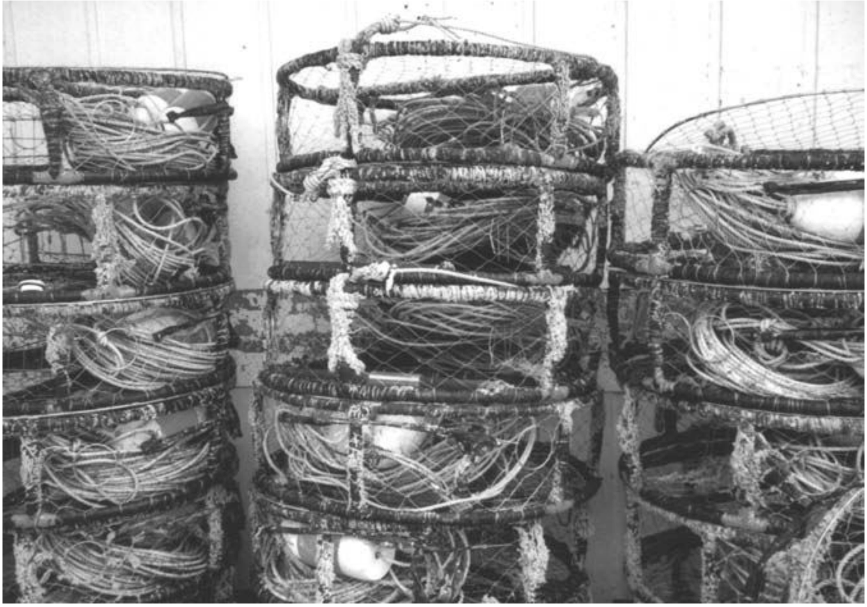


Fig. 13. Pots as used for the harvest of Dungeness Crabs off the Northwest Coast of North America. Pots somewhat similar are used on the Atlantic Coast to catch Lobsters, Spiny Lobsters, and Blue Crabs.

for any given species do not take into account the interdependence of fisheries populations, this approach can be misleading. Furthermore, an MSY estimate fails to recognize that the potential yield is highly dependent on associated environmental conditions. So, for up-to-date management practices, due consideration is given to interactions throughout the supporting ecosystem with an emphasis on the environment as related to the life histories of the species in question. Included is the realization that oscillations affecting the ocean climate can significantly impact fisheries stocks. (See the Addendum to Chapter VI discussing EL Niño, the Pacific Decadal Oscillation and the North Atlantic Oscillation).

Added to the complications to be taken into account is the fact that, for many fishing techniques and especially for most all bottom trawling, there is a considerable by-catch of unwanted fishes and other life that is usually discarded, literally shoveled overboard with much of it dead. This is a very perplexing problem for, while dragging and disturbing the bottom is anything but an environmentally-friendly way to harvest

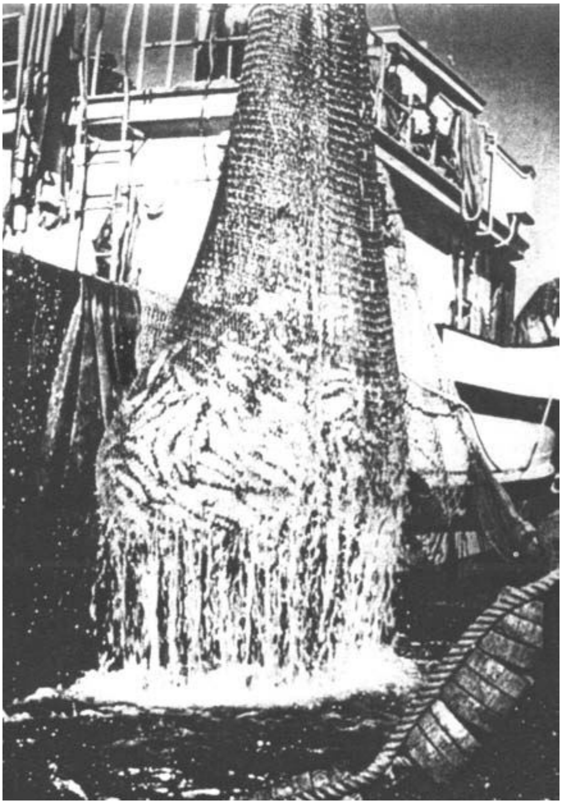


Fig. 14. "Clean" catch of Red Hake being emptied from the cod end of a mid-water trawl. Obviously any trawling off the bottom minimizes the trash fish problem. Photograph by Bill Pearcy.

the living resources of the sea, the harvests outweigh the adverse effects and dragging will undoubtedly remain a very major part of the overall fishery effort. Fortunately, fishers are sometimes successful in finding areas with less trash and proportionately high yields of target species (Fig. 14). Research as to techniques that might reduce by-catch is helping somewhat.

At this point you might wonder just what is the basic problem confronting the fisheries? Is it overfishing or adverse environmental conditions? Obviously, it is some of each, and the mix varies for any given fisheries situation. Take the North Atlantic Cod, for example. The population has become seriously depleted and, under the consensus that this has been due to overfishing, the allowable catch has been greatly limited and actually totally banned in some areas. However, recently, as mentioned under the Addendum to Chapter VI, there is some indication that a high index in the North Atlantic Oscillation has brought about environmental conditions unfavorable to the early stages in the Cod's life history.

To summarize, sound fisheries management is very difficult to achieve. To begin, there are the continuing challenges, unknowns, and remaining uncertainties in the realm of fisheries science. Then there are important economic interests to be dealt with. In addition, there are basic conflicts of interest, with the usual conservation versus commercial and recreation versus commercial tensions that, at times, seem impossible to resolve. Management methods range from catch limits, to size limits (both minimum and maximum), to limited fishery licenses and quotas, and finally, to closing specific fisheries or fishing areas. The potential of marine reserves or no take areas, where recovery might be achieved and spillover to adjacent areas may occur, has been attracting attention lately. Finally, with the emphasis on the commercial harvests that are being monitored, we are not paying sufficient attention to the importance of the small-scale fishing activities close inshore.

In the past, when waters beyond the territorial sea of a coastal nation were considered the high seas and were open to all, many vessels were fishing far from their home waters and close to the coasts of foreign countries. For example, until the mid-1970s, there were large fleets of foreign trawlers on the continental shelf from Eastern Canada to the Mid-Atlantic. Many of these were factory ships from Russia and Western European countries taking advantage of well-known fishing grounds by working distant waters. I could see these fleets as I cruised off Southern New England. I would also see U.S. Coast Guard ships patrolling to keep foreign vessels from fishing inside a so-called 12 mile contiguous zone in which the United States claimed sole fishing rights.

The history of the factory ships is quite intriguing. As fishing vessels go these were enormous, many being appreciably bigger than the one shown here which was developed in England and was reported to be the first of its kind (Fig. 15). In addition to the catch harvested with their own trawls, factory ships typically handled the hauls of smaller trawlers that accompanied them. With mechanical filleting capabilities and the ability to deep freeze a finished product on board, these ships would remain on the fishing grounds for extended periods (Fig 15, 16). They

Fig. 15. Fairtry I, the first factory ship, built by Christian Salvesen Ltd., a company that referred to her as "The Floating Ritz."

were often serviced at sea by ships specializing in repairs, with some even outfitted and staffed to meet medical needs. These big ships and their accompanying trawlers were so numerous on their favorite fishing grounds that, on the horizon and lighted at night, they looked like cities in the distance.

Since the adverse effect of their wholesale dragging obviously was tearing up the bottom, it is a wonder that such large-scale fishing had not literally driven some stocks to extinction. It was fortunate that these giant ships became the dinosaurs of the fishing industry when, in the mid-1970s, vast fishing grounds were closed to foreign ships and they had to search far afield, generally with less success, for areas where they could operate effectively.

It was Chile and Peru that led to the banning of foreign fleets in the offshore waters as they claimed sole rights to the fishery resources out to 330 km (200 mi). Some would say that the extended claims of these South American countries were justified in view of the proclamation by President Harry Truman in 1945 claiming, for the United States, all assets on the adjacent continental shelf. Actually, the assets referred to in the Truman edict were the mineral resources on and under the seabed, not the fisheries resources, not even flatfish taken by bottom trawls. Even so, inasmuch as the shelf off the East Coast of North America is

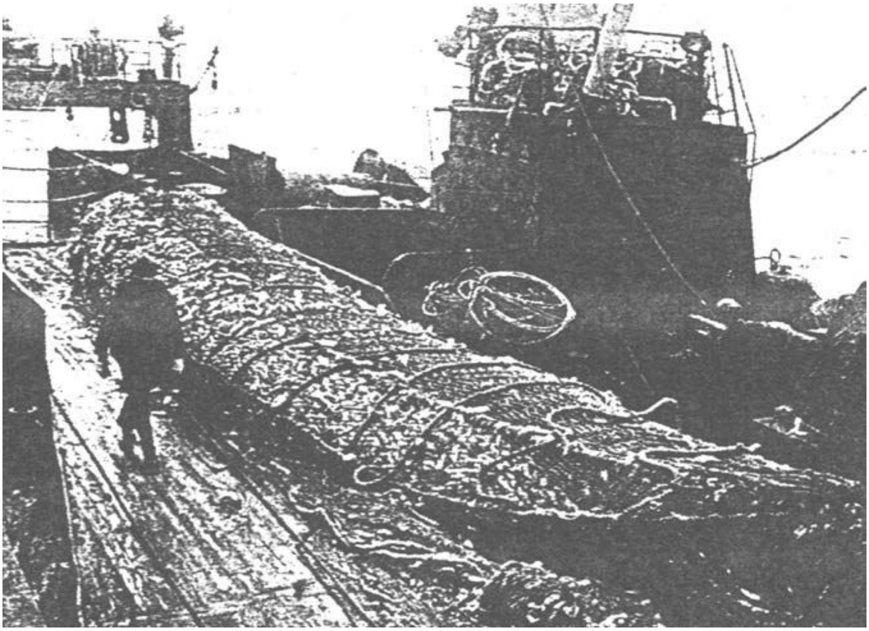


Fig. 16. Massive take of Red Hake in the cod (tail) end of a bottom trawl that has just been hauled up the stern ramp of a Russian factory ship. Source: Greenpeace.

approximately 200 miles wide, it can be said that these South American countries, in prohibiting foreign fishing operations well beyond their territorial seas, were following rather than setting a precedent.

Such conflicting and sometimes confusing policies, not only with respect to the fisheries but involving other practices on the high seas, led to the convening of a comprehensive Law of the Sea Conference under the aegis of the United Nations beginning in 1973. In the Conference deliberations the fisheries issue was settled early on, essentially by granting to each coastal nation an Exclusive Economic Zone (EEZ) extending 200 nautical miles (370 km) offshore[3] in which the control of

3 The EEZ was defined without reference to the width of the continental shift which in some areas extends beyond 200 miles and in others is relatively narrow. Note: When the EEZ is specifically defined, the width is given in nautical miles although extensive literature on this subject, including mention made herein, simply refers to 200 miles.

the fisheries and various other privileges were allocated to the adjacent nation (Fig. 17).[4] This avoided the problem of reversing the rulings of the western South American countries, and, simultaneously, it catered to the expansion ambitions of coastal nations worldwide. It also seemed to be the beginning of a trend wherein the nations of the world were determined to extend their claims wherever possible, thereby forsaking an approach that would have involved a greater sharing of what had been referred to as the potential "Common Heritage of Mankind" (Fig. 18).

The EEZ is not just a "now it's all yours" concept. Nations are obligated to provide for optimal environmental conditions off their coasts. Along with this, they can control the discharge of ballast water and other pollution practices of ships transiting or entering their respective exclusive areas. (See Chapter XVIII discussing pollution.) As to the fisheries, the coastal nations are not just free to harvest without limits. Supposedly they are obligated to manage these resources to assure sustainable yields and even to arrange for fishers from other countries to harvest should there be an excess or, more likely, a particular species not sought after by their own fishers.

One provision of the EEZ has made matters a bit difficult for the oceanographic community, namely, that any party wishing to conduct research in this controlled area off any given country is required to get the permission of and to share the findings with the country involved. In the Caribbean, for instance, this leaves only a very small, central, high seas area where a research vessel can function without any required approval.

Without waiting for the more lengthy deliberations of the Law of the Sea Conference, the EEZ concept became Customary International Law in the mid-1970s. Accordingly, starting in 1976 the United States barred foreign fleets from fishing within 370 km (200 nautical mi) of the coast whereupon U.S. fishing interests quickly moved in. Soon increasingly efficient fishing craft were harvesting the available stocks. Some vessels, notably the fleet fishing for Pollock south of Alaska actually have factory

4 The LOS Convention also includes a provision for a country to lay claim to a jurisdiction beyond 200 miles if the bathymetry beyond the edge of the shelf and continuing on down to the beginning of the deep ocean floor suggests it, or if there is a stipulated trace of the sediment characteristic of the shelf. The procedures required for the review of any such a claim, not to mention the difficulty of substantiating the necessary supporting information, has delayed the consideration of such extended claims. The first three of some seven submissions for consideration are from Russia, Brazil, and Australia.

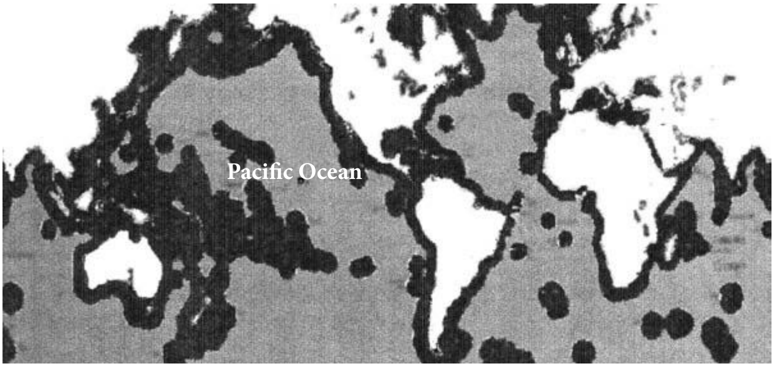


Fig. 17. The continuum, of the Exclusive Economic Zones (EEZ), shown in black around the coastlines of the nations of the world. Source: U.S. Department of State.

ship capabilities, though they are not quite the giant foreign ships that had previously been operating off North America. Such increased harvesting sometimes overshadowed any hope for sound conservation practices, there being a tendency for theofficial bodies charged with managing these fisheries to disregard catch limits recommended by fisheries scientists. Thus the United States, and many other nations for that matter, have not been meeting the obligation to manage the EEZ fisheries (Fig. 19)[5]. The effects of such overfishing have been exacerbated by modernized methods and many fish populations have become seriously depleted.

I find it frustrating to be aware, on the one hand, of the overfishing that has been taking place and then to pick up a typical commercial fisheries magazine and read of the large fishing vessels being built for the industry. Along with this, there is the never-ending development of improved gear and methods. It seems that fishers feel a need for larger vessels and advanced equipment if they are to be successful even though they may be fishing down the very stocks on which their livelihood depends. With fishing being an open access activity, this is a dilemma difficult to deal with.

The deliberations of the Law of the Sea Conference were completed in 1982 providing a document titled the United Nations Convention on the Law of the Sea (UNCLOS) intended to serve as a body of international

5 There have been efforts to improve the provisions for fisheries management in the EEZ. In the U.S. for example, updating the 1976 legislation includes more attention to environmental conditions and a greater emphasis on the advice of fisheries scientists.

Fig. 18. Arvid Pardo, Ambassador of Malta. In speaking before the United Nations in 1967, Pardo introduced the term "Common Heritage of Mankind," applying it to the resources of the sea with the hope that these would be widely shared. Source: United Nations.

law on a broad range of maritime issues. Of course, it included the EEZ but it also covered a great deal more, such as establishing the right of innocent passage through the territorial sea of any given country, providing for unimpeded transit for ships, airplanes and submarines through international straits and archipelagos, and access to the sea for landlocked countries. Provisions for settling anticipated ocean-related disputes were included.

Many nations accepted the Convention at least as Customary International Law. In fact, as with the EEZ provisions, much that was covered in the Convention had already become common practice. By 1994, with the UNCLOS adopted by the required number of nations, it became World Law. Even so, some countries that had accepted the broad scope of the provisions still refused to accept one limited part of the Convention, namely, that which deals with mining the deep seabed for manganese nodules that are rich in copper and nickel. Prominent among these hold-outs are industrial nations, including the United States.

Fig. 19. Large modern trawlers docked at Point Judith. Many of these were built with government-backed loans. Since the passage of the EEZ, other countries have also been subsidizing the upgrading of their fishing fleets. Actually, some of the new vessels fishing in the North Pacific, have on-board processing capabilities though they are not the giants of the old-factory ships.[6]

In general, the nations that are abstaining are protecting the interests of private venture groups that objected to certain conditions and limitations to be imposed on private undertakings in favor of the so-called Enterprise which was to be organized under the International Seabed Authority to mine nodules for the developing world. As most of the objections have been addressed in subsequent deliberations, abstaining countries are beginning to fall in line. In the United States, for example, the LOS has been favorably reported out of Committee and Senate approval may very well follow.

Actually, there has not been any deep seabed mining as yet but, if undertaken, the related provisions should encompass mining for some of the additional minerals such as valued ores at the deep sea vents.

Returning to the focus on the fisheries, certain gaps in the provisions of

6 I am told that Russian factory ships are practically lined up, operating just outside 200 miles south of the Aleutian peninsula.

the Law of the Sea Convention have caused concern. Problems developed relative to the management of fishes that migrate across adjacent EEZ boundaries or simply cross the outer boundaries. Some nations had been addressing problems of this sort for many years. For example, the Pacific Salmon Treaties are agreements between the United States and Canada whereby they share in the harvests of salmon that migrate throughout their respective offshore areas. In addition, there have been adequate agreements relative to the harvests of tuna. However, there were no all-encompassing provisions for trans-boundary and highly migratory fish stocks, and some very difficult tensions were unfolding. In one case, fishers from Spain, trawling just outside the EEZ of Canada, were making serious inroads on Turbot, a species that the Canadian government was trying to manage within its EEZ. The overall issue has been addressed in further deliberations of the United Nations and provisions for regional agreements relating to the conservation and management of such stocks now exist. Some observers tend to think the new provisions are proving difficult to enforce.

As mentioned in Chapter XII, certain tuna fisheries, if not effectively regulated, would take a heavy toll on the dolphin populations that tend to hover over schools of tuna. This is especially true in the Eastern Pacific where Spotted, Spinner, and Common Dolphins are known to congregate over tuna and thereby tend to attract the tuna purse seiners. Currently, such seining, also the loss of dolphins due to gill netting, has been offset by a tuna-safe program, specifying that tunas cannot be marketed unless certain conditions such as the following are met:

- There is no chasing, netting, or encirclement of dolphins during an entire tuna fishing trip;
- There is no use of gill nets to catch tuna; and
- For each trip to the Eastern Tropical Pacific, vessels 400 gross tons and above must have an independent observer on board, attesting to the observance of dolphin-safe regulations.

Most of the world tuna companies are adhering to these standards. To protect the consumer, a "Dolphin-safe" logo is applied for marketing.

In focusing on several of the commercial fisheries, I have not accounted for recreational interests. Actually, you may encounter considerable sport fishing even far offshore as many of the boats involve make long one-day trips. Some are privately owned, some are available for charter, and some are so-called open boats for the public at large.

It had been widely assumed that the quantity of fish taken for recreation is so limited that there is no significant impact on fisheries stocks. However, new analyses indicate that, for the United States alone, if you rule out the fisheries that are almost exclusively commercial, the recreational component of the overall take of marine fishes runs as high as 10%. For certain favored species, with the Red Drum, Bocaccio, and Red Snapper being mentioned as specific examples, the percent can be a great deal higher. Further, it should be noted that the number of people involved in fishing for recreation is very large and, from a financial stand point, sport fishing is very significant.

In your travels be on the lookout for the fisheries practices I have mentioned. You may see others for the fishery resources are very diverse and the fishing techniques vary a great deal throughout the world.

Chapter XV. Seabirds

Birding on the high seas is just great! Obviously you will often want to identify the various species seen. For this I suggest the following by Peter Harrison:

Seabirds, An Identification Guide. 1983. Houghton Mifflin Co., Boston.

Only about 3% of all bird species might be thought of as primarily marine, yet a number of features common to most all birds are well suited for living on the high seas. Two adaptations for flight, namely their light bone structure and their respiratory air sacs, enhance their ability to float on the ocean surface. In addition, their feathers add buoyancy since, from the preening which makes them waterproof, they trap air. Underwater swimmers such as penguins and cormorants have heavier bones and penguins, being non-fliers, do not have air sacs.

Observing the many interesting behavior patterns of the different birds seen at sea can be very rewarding. Consider the following:

- How do they fly? Low over the water, or high overhead? Are they soaring or, perhaps, flapping and gliding? Or, do they fly more or less continuously?
- How does such behavior relate to the air currents over the water?
- How much of the time are they in flight? How much do they rest?
- How does their behavior relate to the time of day?
- How do birds react to the vessel you are on? Do they trail along behind? Do they fly alongside the updrafts? Do they fly briefly

overhead or fly criss-cross a short distance ahead?

- Is the flight directed, perhaps toward or away from a roosting site or nesting locale, or perhaps toward some fishing ground?
- How do they search for their prey and how do they fish? Do they scoop fish from the surface, plunge beneath the surface, or actually swim underwater after their quarry? (Fig. 1) Obviously, intense feeding activity is a sign that an area is quite productive.)

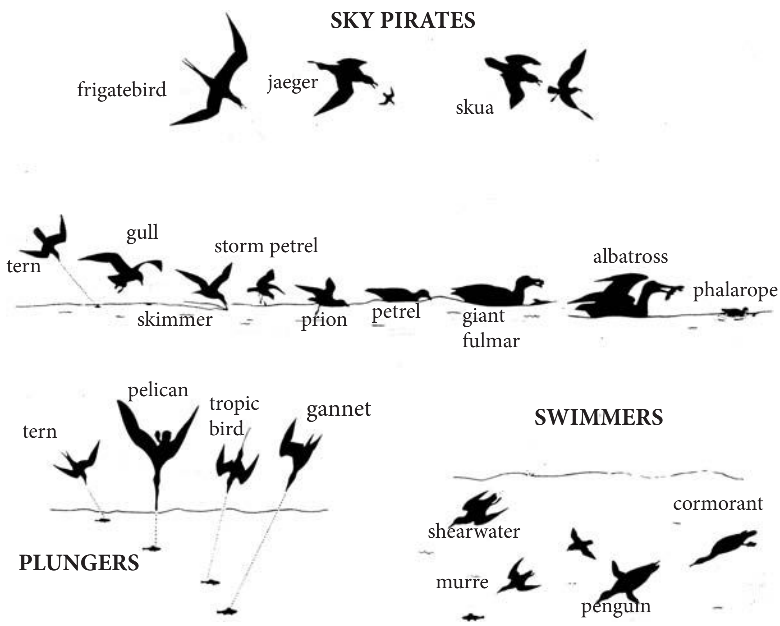


Fig. 1. Feeding methods often observed at sea. Illustration modified by author.

- Do they occur in flocks, pairs, or more commonly as individuals? When in groups, do they fly in formation?
- Are they migrating? Migration can range from travels many thousands of miles to relatively minor shifts in their seasonal distribution. Guidance for extended migrations may involve the stars, magnetic forces, and reliance on landmarks.
- Can you tell that they drink seawater? For most species, the excess salt from their seawater intake is excreted through glands near their eyes. Albatrosses, shearwaters, and other birds in that same group eliminate salt through a tube on the bill. (Think of the lives that

might have been saved if humans cast adrift could drink sea water and expel the salt as birds do.)

- How do various other adaptations relate to the behavior you have observed? Note the different wing types, the specialized bills, etc.
- What other features of bird behavior have you noticed?

To review, some of the highlights of the birds seen while at sea let us start with:

Highly Pelagic Wanderers: Albatrosses, Shearwaters, Storm Petrels, and Diving Petrels

This is the group that comes closest to being truly oceanic, yet they all must return to land for nesting, usually on small islands.

Albatrosses

There are over 13 species[1] of albatrosses, the largest being the great Wandering Albatross which, as an adult, is almost all white with black wing tips and has a wingspread of 3 ⅓ m (11 ft) (Fig. 2). This is the

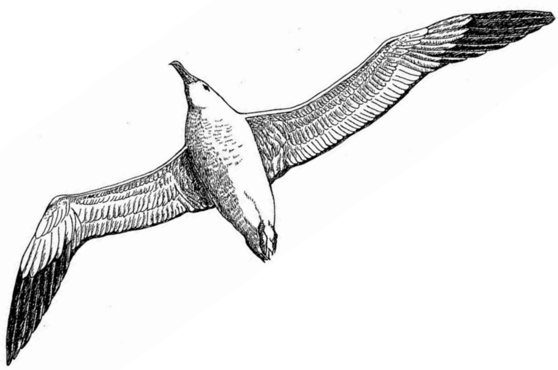


Fig. 2. Wandering Albatross, the champion of all gliders. Drawing by Debbie Kennedy.

1 Since taxonomists are not always in agreement, the number of species recognized may vary from the numbers given through this study guide.

greatest wingspread of any bird, though it is almost matched by the Royal Albatross.

Albatrosses are the unquestioned champions of gliding flight. Their narrow, tapered wings are perfectly designed to glide in the updrafts just above the waves and, given enough wind, they can travel almost endlessly. *Rime of the Ancient Mariner* reminds us that the Wandering Albatross may keep company with ships at sea for days on end. Sailors who, for no good reason regarded them as stupid, refer to them as gooney birds or use other uncomplimentary nicknames.

We know that the Wandering Albatross may actually circle the entire Planet and that other albatrosses make comparable flights. On the other hand, since the airfoil wings of these birds are not suited for flapping flight, they tend to be grounded when the wind drops. This is also the reason that many albatross species thrive in the windiest, roughest seas of the world, namely in the Westerlies of the Southern Ocean. It is only in the Pacific that a few species are regularly found north of the Equator.

The Wandering Albatross may live for 60 and more years and not mate until 11 or 12 years old. The female lays only 1 egg which may take up to 80 days to hatch. During incubation the albatrosses may forage over thousands of miles with males and females taking turns back on the nest. Of necessity, though still wandering, they remain closer to the colony after the eggs hatch. They tend their young for as much as 11 months, feeding them by regurgitating the seafood taken.

Shearwaters, Petrels, Fulmars, and Prions

This is a very large group of about 53 species, including some considered to be among the world's greatest travelers. Since they are not common ship followers, they may be less familiar than some other groups.
The shearwaters get their name from their habit of skimming almost motionless over the sea, some of the time being in the troughs below the wave crests. Most of them are of medium size; some are larger; i.e. 25 to 90 cm (10 to 36 in) long. They have slender, streamlined bodies and long thin pointed wings. They feed by scooping their quarry from the surface. The Slender-billed Shearwater migrates clockwise around the entire Pacific every year.

Storm Petrels

These are the very familiar "Mother Carey's Chickens" (Fig. 3). You can't mistake these little dark-colored birds flittering over the waves. They are notorious ship followers and occur in practically all the open ocean areas of the world. The largest of the 22 species is only 25 cm (10 in) long. Most are solid black or dark brown above and below with a conspicuous white rump. On the wing, they snatch their food from just below the surface. They consume planktonic crustaceans, such as members of the genus *Calanus*, also tiny shrimp, squid, etc.

In waters where they are abundant, they have been known to rain down on ships during the night, apparently confused by the lights.

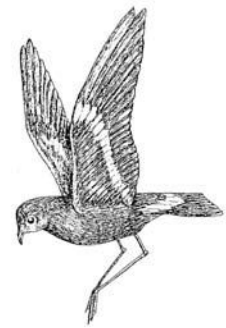


Fig. 3. Wilson's Storm Petrel, well-known as Mother Carey's Chickens. There are several species of these small friendly companions on the high seas. Drawing by Debbie Kennedy.

Diving Petrels

They are chunkier than the storm petrels and they dive and swim for food. They have been known to dive into the crest of a wave and come out flying on the other side. There are only 4 known species; all in the Southern Hemisphere.

A Favorite Sea Bird Group Unique to the Southern Hemisphere: Penguins

The laughable caricaturing of human posturing by penguins is very familiar. There are some 15 species widely distributed in the Southern Hemisphere. They stand upright on land and the largest species of the group, the Emperor Penguin, is about 1 m (~3 ½ ft) tall (Fig. 4). Their wings, modified as flippers, provide for an underwater speed in excess of 22 knots (25 mph) enabling them to chase a diet of fish, squid, and shrimp. Like porpoises, they often travel in schools that leap out of the water in short graceful arcs, which, in Chapter XII, I referred to as porpoising.

Most birds of the sea breed in large colonies and a single colony of penguins may number in the hundreds of thousands (Fig. 5).

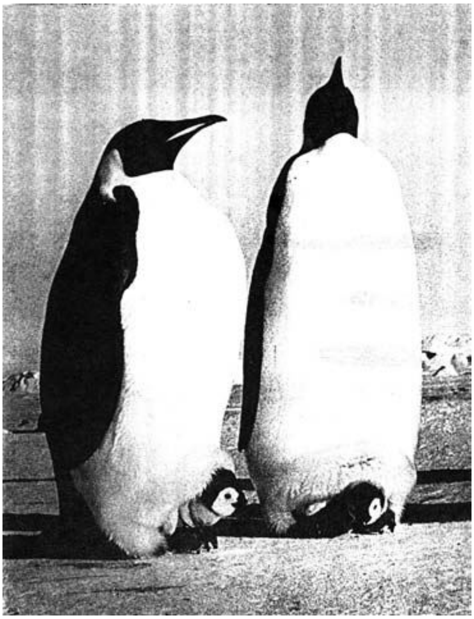


Fig.4. Emperor Penguins with chicks. Source: NOAA.

Fig. 5. Penguin rookery on the Antarctic Peninsula. Source: NOAA.

Fig. 6. Tufted Puffin from the West Coast of North America. Source: NOAA.

Auks of the Northern Hemisphere:
Auks, Murres, Guillemots, Dovekies and Puffins

These are the Northern Hemisphere counterparts of the penguins which they resemble in their ability to swim underwater to capture their prey. However, they have retained their wings and are very strong fliers. An exception was the Great Auk which, being unable to fly, was so readily gathered in large numbers for food and feathers that the species became extinct.

There are some 23 species in the group, varied in size with the largest being only slightly larger than the smallest of the penguins. Puffins, with their gaudy parrot-like bills and looking quite alert, are the delight of sight-seers passing the island colonies where they nest in burrows in the ground (Fig. 6). The reestablishment of a breeding Puffin colony on an island off the central Maine coast is a success story that has received a great deal of attention. The story is quite impressive as it has involved flying young from colonies farther north, placing them in man-made burrows, feeding them, and using decoys to make them feel at home.

Two Groups Restricted to the Tropics: Frigatebirds and Tropic-Birds

Frigatebirds

These are the feathered buccaneers of the subtropical and tropical regions, unquestionably the most agile in flight of all water birds (Fig. 7). No doubt you will be impressed by the red gular pouch of the breeding males which they inflate as though with great pride. There are 5 species generally about 30 cm (~1 ft) long but with a wing span of about over 2 m (~6.5 ft) which is unusually long for a bird of their modest size and relatively light weight. They may live for decades and do not mate until they are 11 or 12 years old, when they lay only a single egg. They tend to their young for some 12 months.

Frigatebirds may be seen soaring motionless far on high. Keep watching and you may see them swooping down to harass other seabirds, such as boobies, pelicans, cormorants, gulls and terns, pecking at their victims and making them drop or regurgitate their food. Frigatebirds are so agile that they may actually catch the food discarded by their victims before it hits the water. Actually they never settle on the water since their wings do not shed water and their legs are far too inadequate to help them take off. It's fascinating to see them using their long hooked beaks to pick up most any food item floating on the surface, all the while remaining completely dry.

Tropic-Birds

There are only 3 species, all within the subtropics and tropics. They look like large white terns but you can readily distinguish them by their two very long, extended tail feathers. They don't linger around sea going vessels but, as they seem to be curious, you may see them circling briefly overhead before going on their way. They dive for squid and fish and quickly reappear on the surface with their prey.

Groups Commonly Occurring Along the Coast But may Be Seen at Sea as well: Pelicans, Boobies and Gannets, Skuas and Jaegers, Gulls, Terns, and Skimmers

Pelicans

The familiar pouches on the underside of their beaks can hold almost 12 L (3 gal). They essentially use the pouch as a dip net, letting the water

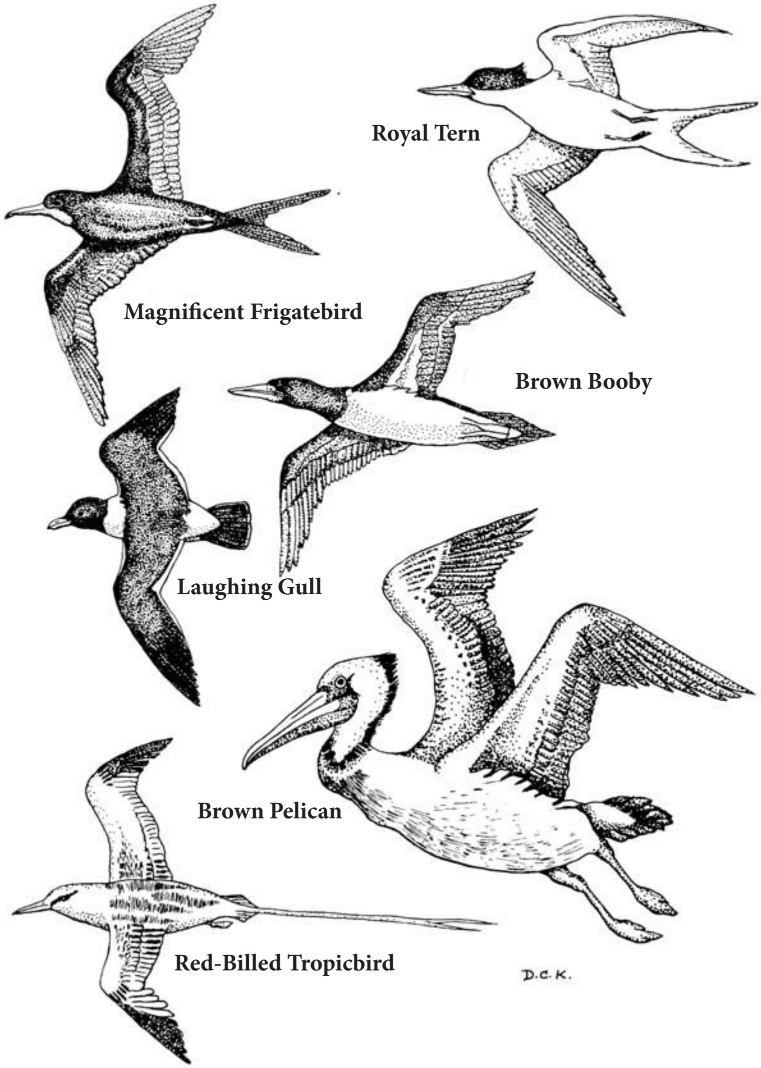


Fig. 7. Birds commonly seen in the Caribbean. Drawing by Debbie Kennedy.

drain out before swallowing their catch.

They are large birds, skilled and graceful flyers often seen traveling in small groups in V formation and not much more than 30 feet above the water. When they fish, they dive at the water making a great splash, yet they seldom get completely below the surface.

The Brown Pelican is the common coastal species you are likely to see. While abundant in the Tropics and Subtropics, it also ranges well into the temperate regions (Fig. 6).

Boobies and Gannets

You may see boobies, 6 species in all, in the tropical waters and gannets, only 3 species, in the temperate areas. Most are about the size of the common domestic goose and, of the two groups, it is only the gannets that migrate to any extent.

As they fish, they plunge on a slant from on high and can submerge to a considerable depth to get their prey. Since they fish in groups you may see them making quite a splash as they hit the water.

Skuas and Jaegers

There is one skua species and three species of jaegers. Both look like large gulls though their dark or brownish plumage, while somewhat similar to that of immature gulls, differs from the predominantly white coloration of adult gulls. In their scavenging ways they act like gulls though they don't follow ships the way gulls do. They catch some fish but are more prone to attack smaller birds forcing their victims to give up their quarry or to regurgitate their food.

Jaegers are somewhat smaller than skuas and are readily distinguished by their elongated central tail feathers.

Gulls

Though generally referred to as Sea Gulls they are seldom found far at sea and they range well inland, congregating in great numbers at garbage land-fills. On the other hand they are so well known for accompanying ships for several miles out to sea before returning, that they should not be overlooked in this review. There are some 43 species and, with the juveniles going through various color changes, it is often difficult to distinguish one species from another. As to feeding, you might say they are the ultimate scavengers.

Gulls can sense available food from a great distance, an ability not uncommon among birds. Probably you have witnessed this on offering a few bread crumbs when there were no gulls in sight only to be besieged within minutes by a hungry army.

One of my friends had a pet wild Herring Gull he named Mabel. When called, she/he would quickly appear, seemingly out of nowhere. Another friend had a Herring gull that would show up, not for food, but simply to ride on the bow of his skiff when he was fishing. This friendship started when the gull had snared a baited fishhook and received much-needed help to get it extricated.

There is one gull subgroup, the Kittiwakes, that differs from the rest as the birds have a quite a range and fish far out at sea.

Terns

Most terns are considerably smaller than gulls and, unfortunately, may fail to compete with gulls when trying to establish a colony on the same nesting site along the coast. There are about 39 species. All are graceful and beautiful in flight and are very adept at spotting schools of small fish near the surface. They then hover and plunge for their quarry. They don't scavenge as gulls do.

Though many terns are basically white with some contrasting gray plumage, the coloration of the Noddies and the Sooties of the tropics is quite dark.

Several tern species migrate great distances from their nesting to their wintering grounds and back. Some Arctic Terns, thought to hold the record for bird migrations, nest north of the Arctic Circle and winter south of the Antarctic Circle, migrating for more than 16,000 km (~10,000 mi) each way.

Skimmers

Skimmers are about 45 cm (18 in) long with scissors-like bills and with the lower bill longer than the upper. You may see them literally skimming the surface of the water for fish and crustaceans. There are only 3 species.

Shorebirds: Plovers, Sandpipers, and Oyster Catchers

Whether these groups, so common along the coasts, should be listed with the seabirds may be open to question; however, as they are so numerous and highly migratory, you may be seeing some species far at sea.

Plovers
There are 63 species all told. They tend to be chunky, strongly patterned, small to medium-sized birds of extremely wide distributions.

Sandpipers
This is a very large and diverse group. The sandpipers and their allies, some 82 species all told, are predominantly birds of the Northern Hemisphere.

Oyster Catchers
There are 6 species of oyster catchers, all about 45 cm (18 in) long. If you can get a close-up look notice their long, vertically flattened, red bills that function much like the knife we use to open oysters. They open oysters, mussels, and clams, and can even chisel limpets off rocks.

In addition to the pelicans, terns, gulls, and shorebirds already mentioned, you may, when close to the coast, also be seeing ospreys, cormorants, quite a variety of sea ducks and bay ducks, ibis and spoonbills, herons, egrets, vultures, and much more.

Land-based birds sometimes become fatigued when migrating long distances over open water. It is not uncommon for an exhausted migrant to take refuge on a vessel far at sea. Such a visitor may stay aboard several days before recuperating and taking off. Or has it really recuperated? One is left to wonder! (Fig. 9)

In the *Raft Book*, which is rich with clues as to how to find one's way if cast adrift in a life raft or under equally difficult circumstances, Harold Gatty suggests that, if a given species is breeding and thus is seen in increasing numbers, land is probably not far away. Sometimes, as you see birds flying in a seemingly determined direction at dusk, you may assume they are headed for a nesting or roosting area. For instance, since Frigatebirds never alight on the water, following just one bird at dusk may guide a sailor to land.

Fig. 9. Migrating Great Blue Heron taking a rest on a vessel at sea. Source: NOAA.

Chapter XVI.
The Fascination of Coral Reefs

The marine life to be seen in a luxurious coral reef community ranks as one of the great wonders of the natural world. Be sure to visit a good reef if ever you have the opportunity.

It can be quite a challenge, however, to cross a barrier reef or the outer rim of an atoll to anchor in a protected lagoon (Fig. 1). If available, charts with well marked channels make the approach relatively safe and easy, and good cruising guide information can help. Lacking such aids smooth water between the breakers of an outer reef may suggest an opening where you might find your way in by sighting from high in the rigging. Finally, I have heard of places where local residents meet visiting boats to welcome and guide them in. I must add that, when traveling where there are coral heads or other dangerous shoals, it always helps to keep a high lookout. Also, it helps to avoid being underway in shallow waters when the Sun is low and reflecting off the surface. Unfortunately, it can be difficult to distinguish between the shadows of the clouds on the surface and the dangerous patch reefs below.

Reef communities, when in a healthy state, are structurally the most complex and taxonomically the most diverse of all marine ecosystems. In this respect, they are comparable to mature tropical rain forests. Also, as in the forests, their gross productivity is extremely high. It's all there to be seen by snorkeling or SCUBA diving (Fig 2, 3).

Where the island shoreline is rocky, there may be an impressive fringing reef; offshore there may be a barrier reef; and patch reefs may occur in the lagoon behind the barrier. (See Fig. 14 for a photo of a patch reef). The most luxuriant communities will be found where

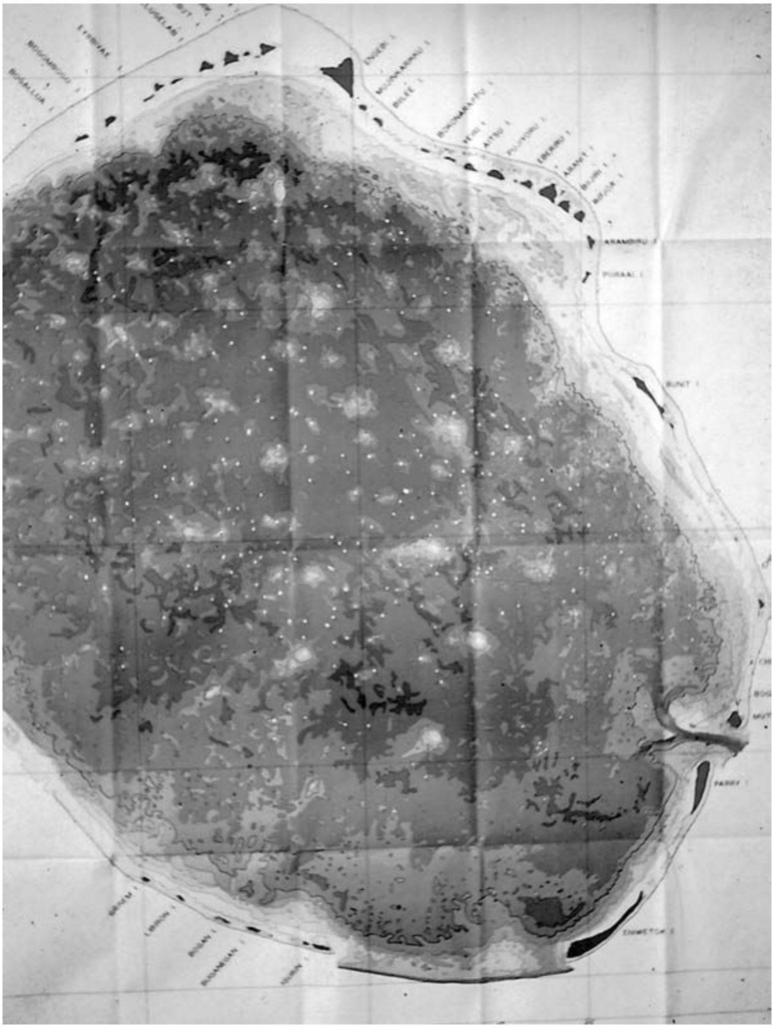
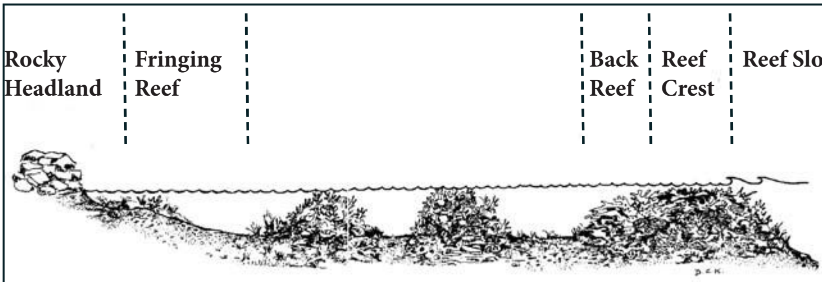


Fig. 1. Chart of Eniwetak Atoll in the Marshall Islands of the Mid-Pacific. The dark tongue in the lower right is a deep pass through the windward reef. Though this channel is unmarked, it is easy to find by the break in the waves crashing on the crests of the outer reef. The water in the channel was so clear that we could easily see the bottom in water 45m (150 ft) deep.



Simplified Transect Across Barrier Reef and Lagoon

Fringing reef may be somewhat similar to back reef, with some seagrasses and algae. Where barrier reef and lagoon are not present, fringing reef may be broader and with some of the coral types of the crest region. Fringing reef development tends to be poor or lacking in front of beaches.

Lagoons vary in width and depth. The floor is typically calcerous sand with a scattering of small corals and seagrasses. Patch reefs may be smaller than shown, permitting the transit of small vessels behind the reef.

Back reef development may include staghorn, millipore, finger, and small boulder corals. Considerable sand and rubble may be present off the back reef slope into the lagoon.

Reef crest may have an impressive development of elkorn corals with an intermixture of star, brain, pillar, and millipore corals.

Reef slope may be characterized by elkhorn corals giving way down slope to more boulder corals and finally mixed coral rubble.

Fig. 2. Drawing by Debbie Kennedy.

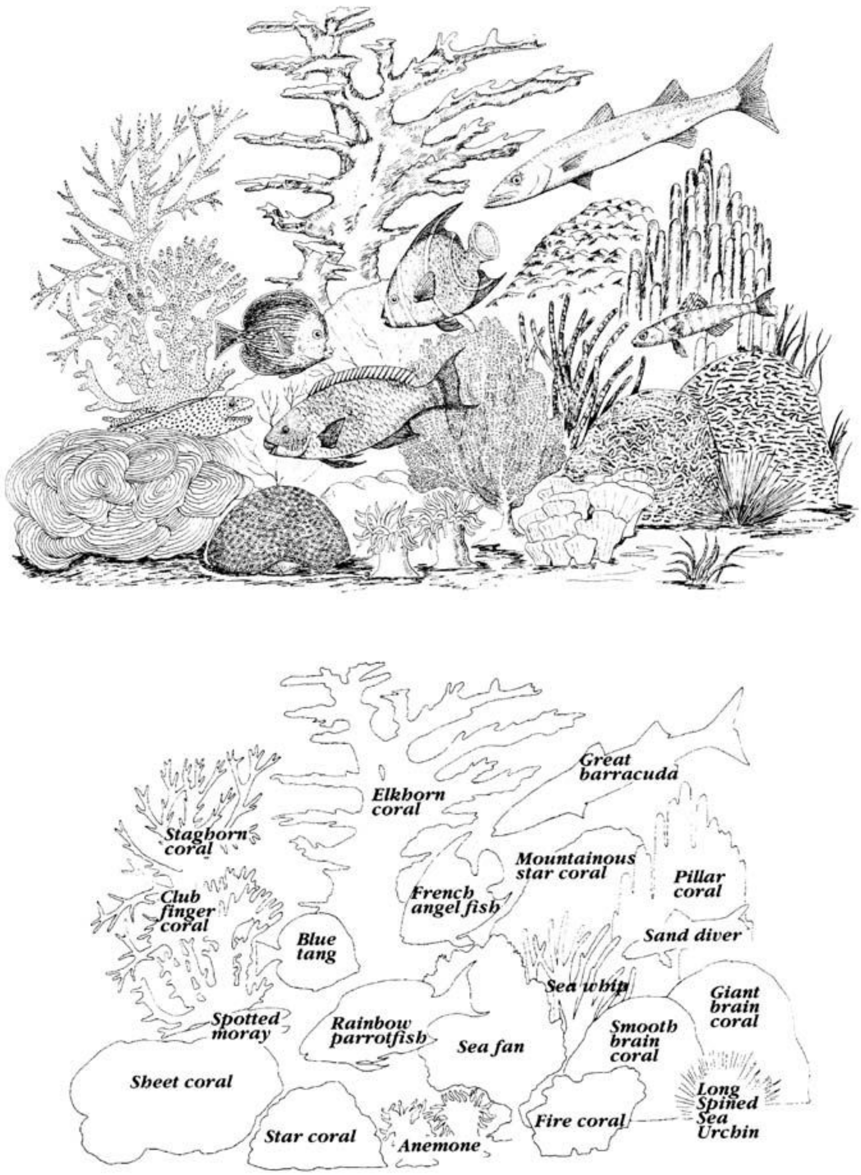


Fig. 3. Coral Reef community. Drawing by Debbie Kennedy.

there is the greatest exposure to waves and currents—a windward barrier reef being especially impressive.

Now let's get down to basics. As living organisms, corals function as both plants and animals. What you first see as you look at the corals is their calcium carbonate skeletal structure. With a closer look, you see that holes in the skeleton, sometimes rather small, are filled with polyps, these being the animal component as shown in the accompanying sketch. In the polyps, there are dense populations of microscopic one-celled algae, the plant component, called zooxanthellae (Fig. 4).

Here we have what is known as a symbiotic relationship, where life forms live together for their mutual benefit. Ample quantities of the carbon dioxide (CO_2) needed for photosynthesis by the zooxanthellae are available from the surrounding seawater and the respiration of the polyps. (See the equation for photosynthesis in Chapter IX discussing plankton.) In turn, the zooxanthellae, through their productivity, provide nourishment for the polyps that harbor them. Also, the carbon dioxide uptake involved in the photosynthetic process causes the soluble calcium bicarbonate present in the surrounding waters to shift chemically to insoluble calcium carbonate thereby enhancing the skeletal growth

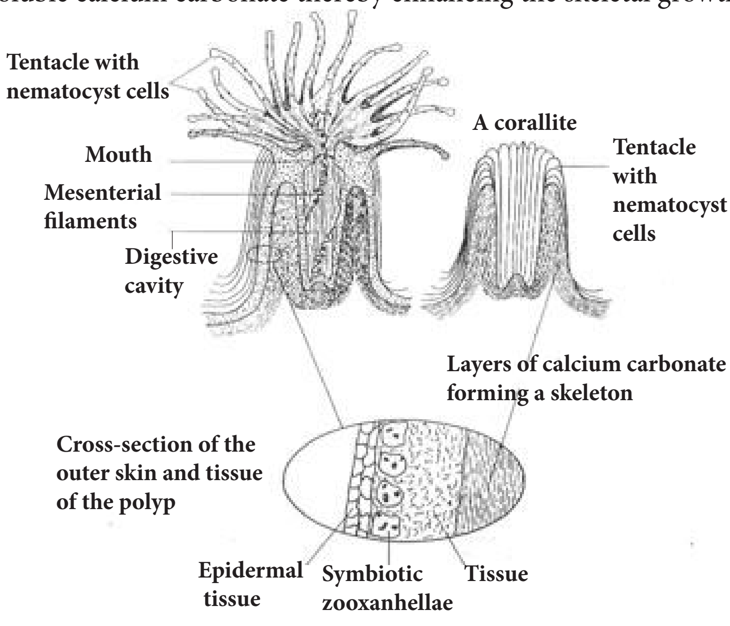


Fig. 4. Cross section of a coral polyp expanded from within the calcium carbonate base. Source: Neshbya, Steve, 1987. Oceanography. John Wiley and Sons, Inc.

around the polyps.

Many corals have a yellowish–brown appearance resulting from their embedded zooxanthellae. Added color is characteristic of some species. However, when for some reason, the zooxanthellae are expelled and the white of the polyp tissue and the surrounding calcium carbonate prevails, the corals look bleached. Coral bleaching, taking place rather extensively lately, is of great concern for it tends to be associated with increased temperatures in the surface waters. Thus bleaching may be a symptom of global warming and may result in the weakening of the coral skeletal material (Fig. 5). (See further discussion of global warming in Chapter XVIII.)

Now how do the coral skeletons form reefs? This is more complicated than you might think. The essential building material consists of the break-up of coral skeletons plus fragments from a wide variety of organisms that have calcareous skeletal parts. The resulting carbonate material is compressed and cemented together to form the reef foundation. To some extent the bonding of this reef material is aided by red encrusting algae which also secrete insoluble carbonate. Continuing

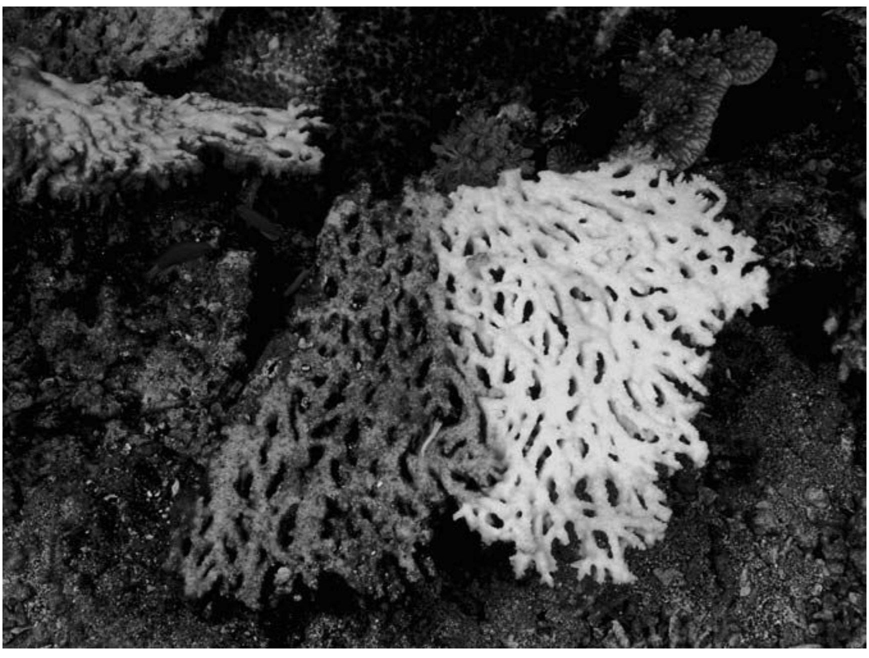


Fig. 5. Partially-bleached coral. Photo courtesy of Wolcott Henry 2005/Marine Photobank.

to build on this foundation, the reef can become a massive structure and in some places raised reef surfaces can be somewhat like rough pavement. Once established, the reefs, with their coral communities, have the potential to grow upward at a rate sufficient to keep up with anything but

Fig. 6. The crest of the windward reed at Eniwetak Atoll. A typical reef front groove appears on the left.

Fig. 7. The windward reef at Eniwetak Atoll as seen as looking north from a tower on Japtan Island built upon the reef foundation.

Fig. 8. Jay Moore (left) and another colleague wading on the consolidated reef platform behind the windward reef at Eniwetak Atoll.

Fig. 9. Massive reefs off the coast of Port Moresby, Papua New Guinea. The pass between the reefs is an entrance to a protected port.

an unusually rapid rate of rising sea levels (Fig. 6-9).

Where, across the world's oceans and along the coasts, will you encounter reef-building corals? The answer: stony corals and coral communities may thrive in the shallows wherever the temperature seldom drops below 18° C (64° F). This is generally within 30° to the north and south of the Equator. Communities can get started on most any firm substratum, even quite far below the surface if the water is clear enough to allow for the penetration of light required for photosynthesis. However, the coral communities often fail to compete with luxuriant growth and cover of fleshy algae, which tends to dominate where there is a considerable nutrient supply. Accordingly, coral reef communities thrive, for the most part, in relatively nutrient-poor waters yet do quite well with the uptake from large volumes of water flowing by. The tight recycling of nutrients plus the presence of nitrogen-fixing organisms on the reefs helps to offset the low nutrient levels.

In the Atlantic, reefs are common throughout the Caribbean, in the Bahamas, and along the Florida Keys. Coral communities flourish far to the west in the Mid- and South Pacific, and in shallow areas of the Indian

Ocean. The Great Barrier Reef, extending in the order of 1,600 km (1,000 miles) along the Northeast Coast of Australia is one of nature's most spectacular formations.

The geological story of volcanic peaks that have subsided and left a rim of reef in the form known as an atoll was elaborated on in Chapter I. There it was pointed out that Charles Darwin unraveled the mystery of atoll formation by piecing together observations he made while sailing by on the voyage of HMS *Beagle*. If you are traveling in seas where the atolls are common, you too will also see volcanic island peaks fringed with reefs, islands with an offshore barrier reef surrounding a lagoon, and atolls where former islands have submerged beneath the surface leaving just a ring of reefs. Often there are low sandy islands built up on the rim of the atolls. The presence of numerous volcanoes in the far western seas has provided many sites for reef and eventual atoll formation (Fig. 10, 11).

In closing this discussion, it is interesting to note that *true* atoll formations are a rarity in the Atlantic. Hogsty Atoll, an isolated formation in the southern reaches of the Bahamas, and Rocas Atoll off the coast of Brazil are outstanding exceptions (Fig. 12). The word *true* is in italics because there are formations that have many of the features of an atoll though they have not developed from subsiding volcanoes. Glovers Reef off Belize is a good example of an atoll-like formation built up on a different foundation.

While the foregoing accounts of reef-building apply to the shallow water communities of the tropics and subtropics, there are small, isolated coral colonies in the temperate regions that do not build reefs but are simply attached to the rocks along the shore. Several of us at the University of Rhode Island used such temperate zone colonies of the coral genus, *Astrangia*, for laboratory studies. We were taking advantage of the fact that the abundance of zooxanthellae in their polyps varied and we could compare the growth of colonies with greater or lesser densities of these symbionts.

Finally, there are corals that, not having any zooxanthellae, do not carry on photosynthesis as is essential for reef building. Some of these live well below the level of light penetration, often far to the north and south.

In the reef communities there are corals with upright skeletons sort of like small shrubs; others are more like boulders with some vaguely shaped like the human brain. Some are thin, almost leaf-like; and there are various smaller skeletal types (Fig. 13, 14).

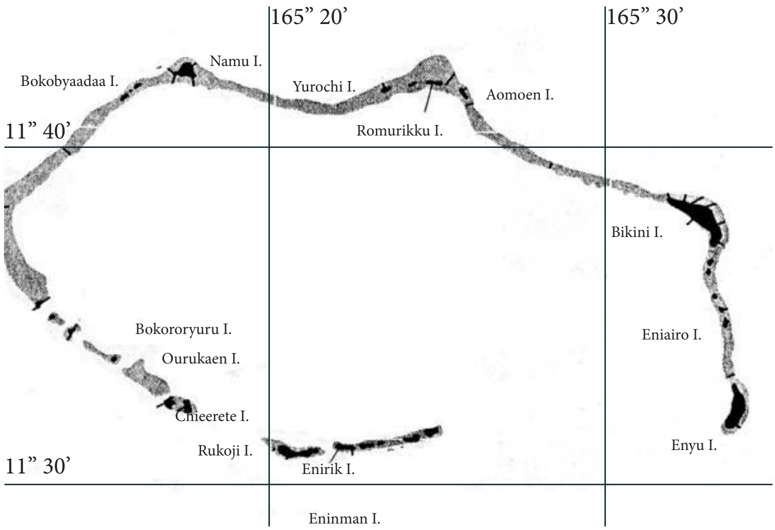


Fig. 10. Bikini Atoll in the Marshall Islands. Source: U.S. Geological Survey Professional Paper 206 A.

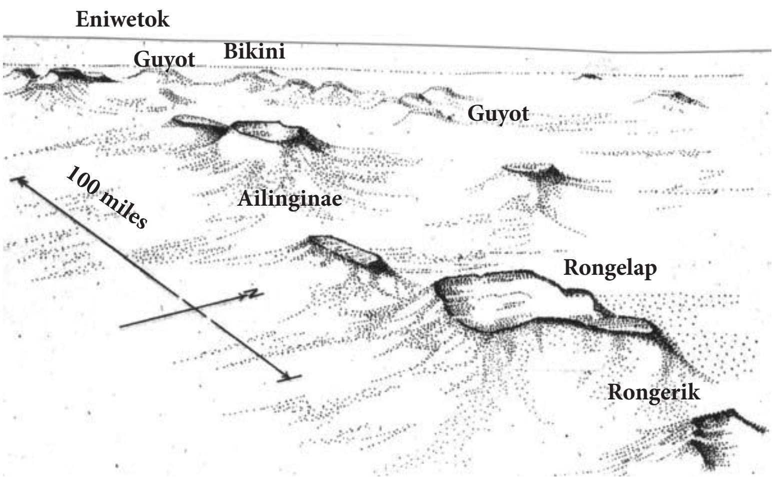


Fig. 11. A schematic elevation of several well-known atolls. A few guyots are shown where volcanic islands have subsided but the reefs have failed to grow to the surface. Source unknown.

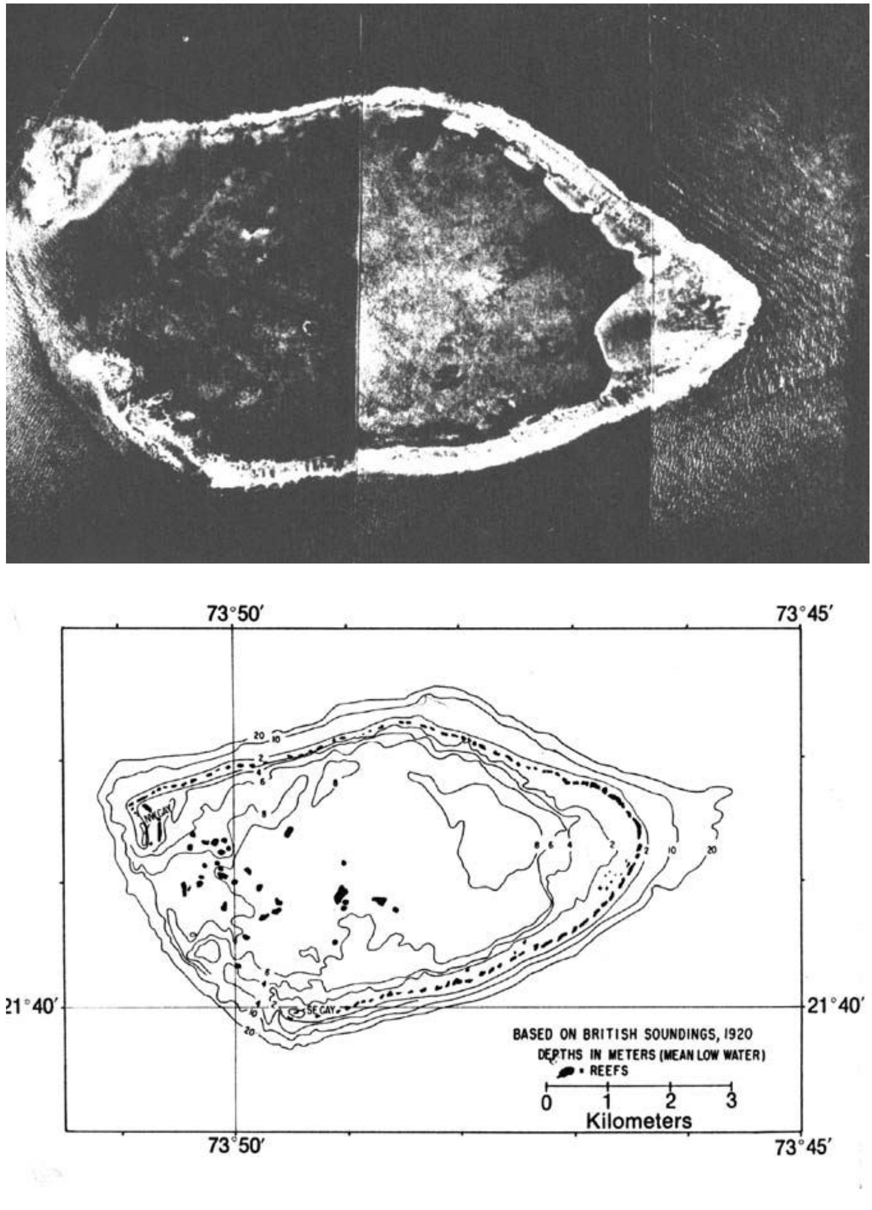


Fig. 12. Hogsty Atoll in the Bahamian Archipelago. Illustration prepared by J.D. Milliman in Bulletin of Marine Science.

Fig. 13. Elkhorn and other corals on a reef crest. Sea Whips appear in the background. Photo courtesy of James R. Sears.

Fig. 14. A patch reef at Eniwetak Atoll.

Though these corals of various sizes and shapes and the multitude of reef fishes typically dominate the seascape, you will quickly appreciate that the reef community is teeming with other life. The anemones, the sea fans, sea whips, and other Gorgonians that are present and very abundant in some areas, are relatives of the stony corals but have little or no skeletal elements. During the day you may see their expanded polyps and their tentacles waving to capture passing zooplankton whereas, except during the night, the stony corals expand very little from within their skeletal framework.

Sea cucumbers and sea urchins abound in the reef communities (Fig. 15). Don't let the waves wash you against the Long-spined Urchins. I did once, and once was enough. As I was enduring the pain, a fisherman passing by advised that the best relief was "to piss on it." Since the spines were embedded in my side this was not easily done. In order to extract the needles, I had to engage in small-scale amateur surgery.

As you continue to explore a coral community you may see some interesting molluscs. Giant clams and smaller related bivalves are quite

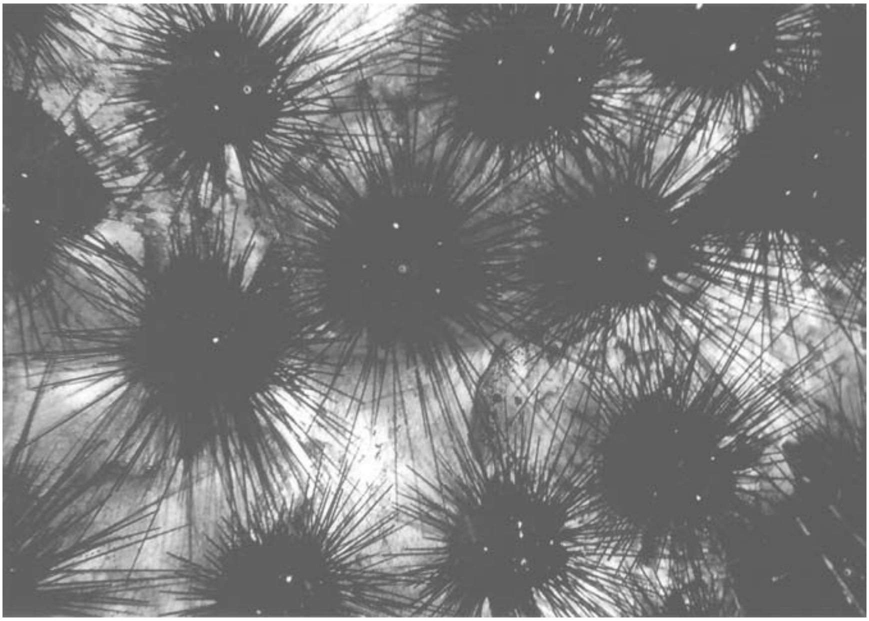


Fig. 15. Long-spined Sea Urchins—Beware!

common in the Pacific.

Fast moving squids may swim by and may put on quite a show with their remarkable ability to change color. The squid's cousin, the octopus, may be seen squirming amongst the corals. Moray eels may be seen poking out of the crevices and maybe you will get a glimpse of a Spiny Lobster or two, though they are fairly well hidden.

If you have a chance to explore the reef at night, you will find that, not only the stony coral polyps but many inhabitants of this complex and rich community, have become more active. On the other hand many of the fishes have apparently gone to sleep. Should you see a sleeping Parrot Fish you will note that it may be enveloped in a protective mucous cocoon.

Skates, rays, and sharks of all sizes may be abundant around the reefs. As to the sharks, even the large ones are not likely to be aggressive and dangerous. (A discussion of sharks and possible shark attacks was covered in Chapter XI and the Addendum thereto.)

Of the varied occupants of the reef community, it is obvious that the parrot fishes are especially important in the breakdown of coral skeletal material needed as a first step in reef building. You may see parrot fishes nibbling on the corals with their horny beaks and see scars on the coral heads where they have been scraping so as to feed on the coral tissue. Their impact is all the more evident if you follow a parrot fish and see a white cloud of carbonate particles being expelled from its vent.

You may also notice various species that bore into the corals. Small sea urchins lie in little pockets they have carved in the coral skeletons. Note also how boring sponges are taking a toll. The common sight of Feather Duster worms peeking out of the coral heads hints that all is not solid within (Fig. 16). When you find some dead coral heads (Don't sacrifice the live ones) turn them over; break them open; and see what you encounter—more worms, crustaceans, brittle stars, etc. You may also see bands of filamentous green algae embedded within the heads where they get the minimal light needed for photosynthesis. This internal mix of biota adds further to the breakdown of the corals, helping to provide the ground-up calcium carbonate that is compacted into the reef foundation.

Today, unfortunately, coral reefs are under increasing stress in many areas. Alina Szymant who, as a graduate student worked with us at the University of Rhode Island on studies of *Astrangia* and has since become a world-renowned reef expert, has referred to the present loss of reef areas essentially as follows: "...degraded coral reefs

Fig. 16. Feather-duster Worm.

generally exhibit a shift from high coral cover (low algal cover) to low coral cover with an accompanying high cover and biomass of fleshy algae." Multiple causes for such a shift include coral bleaching associated with global warming, overfishing with the consequent absence of fishes that feed on fleshy algae, the population decline of certain sea urchins that eat algae, and added nutrients where pollution along the coast favors algal growth. Finally, storm damage, freshwater runoff, and silt may completely destroy a reef.

It's a grim outlook, yet there are many locations where you can experience luxuriant, surviving coral reef communities, particularly if you are roaming in out-of-the-way places.

Chapter XVII.
Stars for Gazing and Navigation

Perhaps there is nothing more enjoyable or more inspiring than a clear night at sea with a refreshing, warm breeze and with the planets and stars showing brilliantly from horizon to horizon. A beautiful moonlit night can be just as thrilling.

On such a night you might be reminded of the early Polynesian navigators who learned that specific stars were at times positioned directly over certain islands and who used this information to guide them on their distant voyages (Fig. 1, 2).

The Polynesians had a number of other useful clues which, all told, enabled them to find their way amongst the distant islands of the South and Mid-Pacific. For instance, they were aware that, in contrast to clouds moving across the sky, those rising over an island or atoll tended to remain where they were forming; furthermore, at times they could even see lagoons and coastal formations reflected on the underside of such stationary clouds (Fig. 3).

From refracted wave crests, they could sense that the waves were dragging the bottom, very likely due to a nearby island. (See the illustration of refraction in Chapter III.) Guidance from bird behavior ranged from their knowledge of bird migratory routes to sensing the proximity of land from the presence of certain species such as terns. Finally, they sometimes released captive Frigatebirds and followed them to a landfall. Without a written language, methods of this sort were the secrets of the native navigators and were commonly passed on from father to son (Fig. 4).

The great colonizing voyages by these natives of the Pacific were

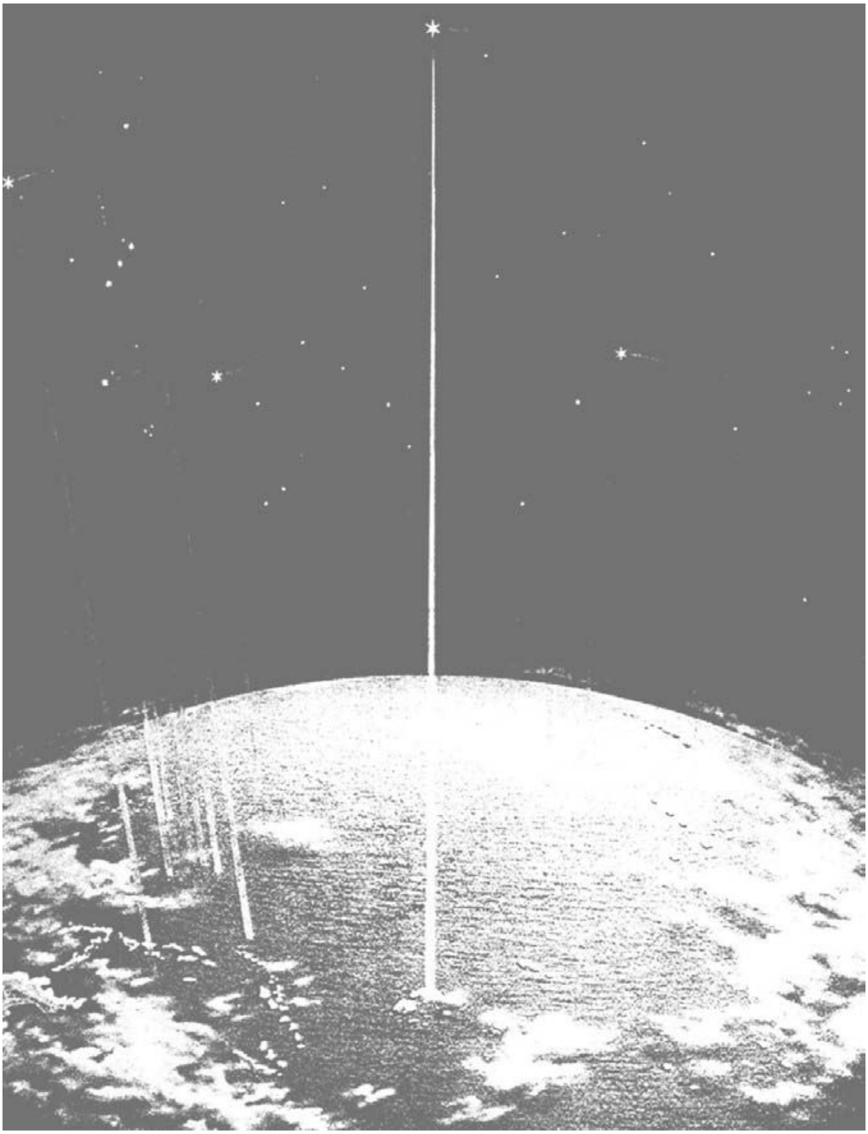


Fig. 1. Stars located over islands as used by Polynesians for navigation. Source: Gatty, Harold 1941. The Raft Book. George Grady Press, New York.

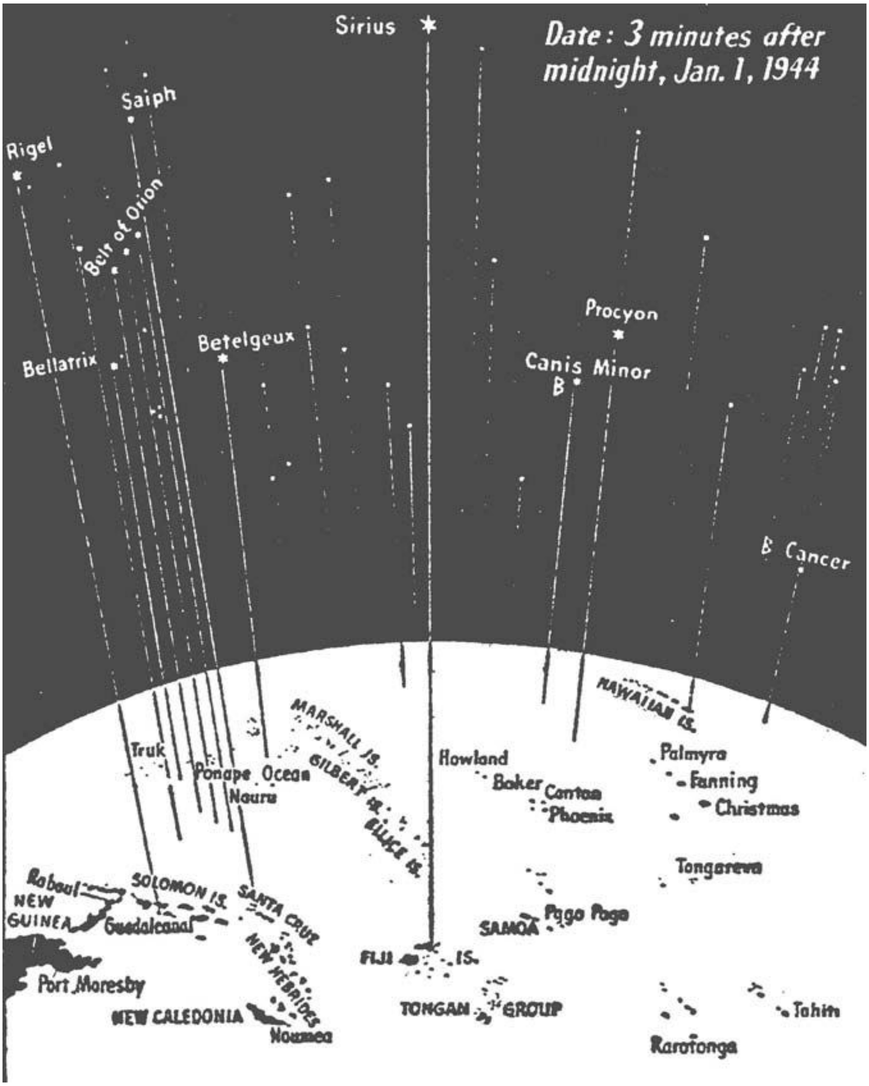


Fig. 2. Identity of stars and islands shown in the previous figure. Source: Gatty, Harold 1941. The Raft Book. George Grady Press, New York.

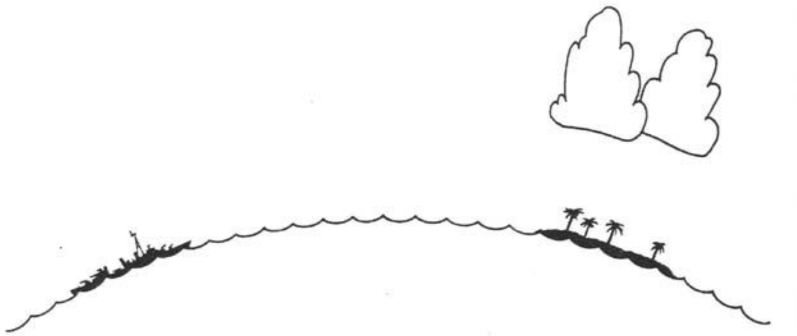


Fig. 3. Stationary cloud over an island. Source: Gatty, Harold 1941. The Raft Book. George Grady Press, New York.

actually carried out well before Columbus crossed the Atlantic. And the knowledge they had acquired relative to the stars was especially impressive, for they were applying some aspects of the advanced practice of celestial navigation that were developed later by mariners of the Western World.

The early European navigators had no difficulty in determining latitude from the maximum altitude of the Sun at mid-day. Also, when in the Northern Hemisphere, latitude was determined from the elevation of the North Star which is within one degree of being directly over the North Pole.

Except for the North Pole, the position on the Earth's surface that is directly beneath a celestial body is continually changing due to the rotation of the Earth. So, if you are to use a sextant reading of a celestial body to plot your position, you must know just where on the Earth's surface that body was positioned at the time you took the reading. This is known as its ground position or GP and, for the 0° meridian which runs through Greenwich, England, the GP is given in the Nautical Almanac for the Sun, Moon, 4 planets, and 57 stars[1]. To apply this information in searching the Almanac for the GP of a celestial body you are sighting, you must know the time at the 0° meridian when the reading was taken. This means that you must have a time piece on board that can maintain Universal Time, as the time at Greenwich is now called.

1 The Nautical Almanac is produced jointly by Her Majesty's Nautical Almanac Office and the United States Naval Academy. However, because of yearly changes in the movements of celestial bodies, it is necessary to use an Almanac for the current year.

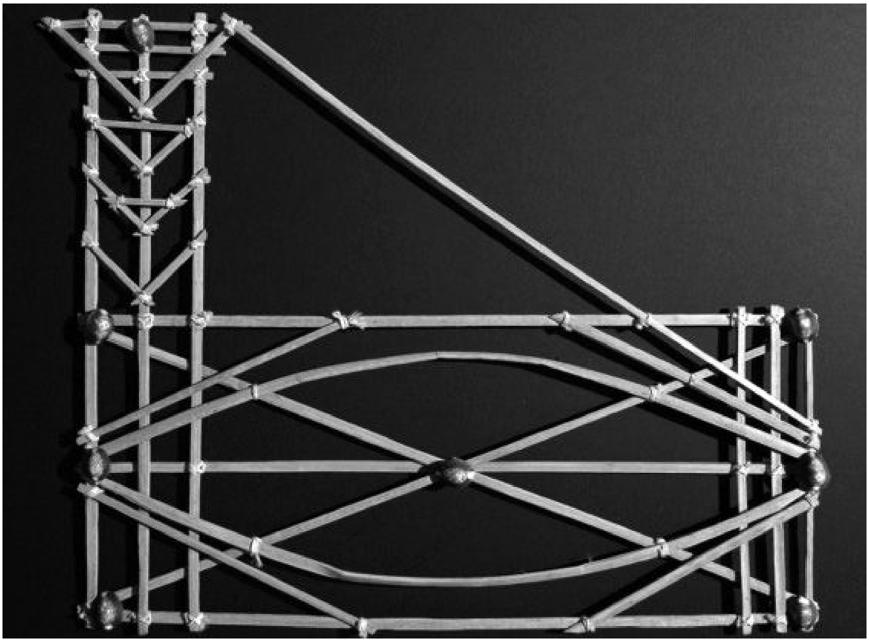


Fig. 4. Stick chart. Polynesian navigators of Oceania were trained to interpret these as indicators of islands and wind and sea conditions. Source: NOAA.

The idea that a time piece, ultimately in the form of a very elaborate watch, could serve this purpose was considered a virtual impossibility, except in the mind of a certain humble watchmaker named John Harrison whose life's efforts were directed to developing what became known as a chronometer[2] (Fig. 5). As perfected, this instrument keeps extremely accurate time at sea, even when it is subject to changes in temperature, barometric pressure, variations in humidity, and, worst of all, a vessel's rolling and pitching motion. Furthermore, to the slight extent that such a chronometer gains or loses fractions of a minute, this is predictable and can be accounted for.

Somewhat ironically we now find that radio time signals from

2 Early in the 18th century the British government offered 20,000 pounds for anyone who could develop the means to tell time on a ship traveling far at sea. Learned astronomers advocated procedures that depended on certain rhythms evident among various celestial bodies; however, none of these suggestions proved to be feasible for observations on board a ship at sea. Harrison's 4th clock, produced in 1761 and referred to as a chronometer, met the requirements, and he was ultimately given the reward he had truly earned.

reference stations coupled with a watch with a quartz crystal, perhaps as simple as an ordinary wrist watch, will serve as well as the most expensive chronometer.[3] There are several reference stations providing the necessary time signals, including WWV in Fort Collins, Colorado, WWVH in Kauai, Hawaii, and CHU near Ottawa, Canada. The latter broadcasts in both French and English.

Celestial navigation involves working on a chart of your approximate location. Start with a dot that represents your best estimate of your location. Then take sextant elevations on three celestial bodies. Immediately record the elevations and the local time, taking into account the intervening time zones, each spanning 15° of longitude, convert local time to time at Greenwich, in other words to time at 0° latitude. Then, from the Almanac, find the ground position (GP) of each of the three celestial bodies you have sighted. Mark these on the chart.

You now have your estimated position and the distances to the GPs of each of the celestial bodies. Using the relevant distances as radii, draw circles around each GP. There will be two intersections of these circles: one off the chart which you will ignore, and another which includes your position. Short segments near the intersection of these circles are straightened out and referred to as Lines of Position (LOPs) (Fig. 6). In essence, these intersections in the form of a triangle, determine where you are located in the circles you have drawn.

If conditions are favorable for celestial navigation, with clear horizons, clear skies for sighting the stars, and seas calm enough so the sextant elevations are measured from a steady footing, the triangle may be quite small and the experienced navigator can be confident that a dot within the triangle is within 3 km (2 mi) of the vessel's true position.

Today celestial navigation by sextant has been superseded by satellite-based navigation using what is known as GPS (global positioning system). Even so, many going to sea still learn celestial navigation. It is part of the tradition of the sea and simultaneously adds to one's appreciation of the celestial bodies. Furthermore, being able to navigate by the stars provides a back-up for a GPS with a low battery or some other failure.

3 At a local nautical supply store I learned that, though quartz crystals are now used in chronometers, most navigators are simply buying clocks governed by such crystals, all nicely dressed up in boxes giving the appearance of more expensive instruments. The store was also selling wrist watches to use for celestial navigation. One model was designed to be continuously corrected by the radio time signals.

Fig. 5. Harrison's ultimate chronometer, known as H-4. Source: National Maritime Museum, London.

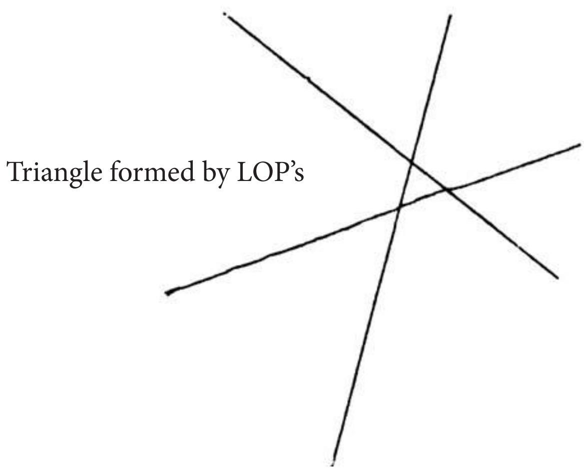


Fig. 6. The triangle as formed by the intersection of three Lines of Position (LOP's) drawn on a navigation chart.

Whether involved in celestial navigation or simply wishing to enjoy the night sky, you will want a suitable rotary star chart or a star base. Such guides, typically for mid-latitudes to the north and to the south and providing templates for finding the prominent celestial bodies by the month and for every hour of the night, are generally available in nautical supply stores.

Undoubtedly, the most familiar constellation in the Northern Hemisphere is the Big Dipper, Ursa Major, easy to find if you face north on any clear night (Fig. 7). The two stars at the end of the Dipper point directly toward the North Star, Polaris. The Little Dipper, Ursa Minor, with its handle curving to end in the North Star, is not as readily seen.

Unfortunately, there is nothing in the Southern Hemisphere comparable to Polaris, though the Southern Cross, which can even be seen from latitudes a bit north of the Equator, does point in the general direction of the South Pole (Fig. 8). Once oriented toward the South Polar region of the night sky you may see two neighboring galaxies looking like clouds made up of stars and known as the Large and Small Magellanic Clouds. We, of course, are in a galaxy known as the Milky Way and, while there are virtually endless other galaxies in the universe, it is unique to find these two that are close enough to be readily identified.

Looking north at night in the higher latitudes of the Northern Hemisphere you may see a beautiful effect in the sky known as *Aurora Borealis*. The phenomenon occurs as high-energy charged particles ejected from the Sun collide with gases in the Earth's atmosphere. This is a somewhat ghostly display of light which may take many forms: streamers, rays, arcs, curtains, and much more. Also, the color of the display varies a great deal. The *Aurora* may range from about 60 to 600 km (40 to 400 mi) above the Planet and sometimes much higher. Do you suppose astronauts get a front row seat when it comes to viewing Auroras?

The term *Aurora Borealis* is synonymous with the less technical term *Northern Lights* (Fig. 9). In the Southern Hemisphere the parallel phenomenon is referred to as *Aurora Australis*.

When in the lower latitudes you should take advantage of the frequency of clear horizons and look for a green flash that may be seen at sunset. It occurs just as the Sun dips below the horizon. To see the green flash becomes a bit of a challenge since it is almost instantaneous. If you happen to blink at the wrong time, you miss it. The atmosphere above the setting Sun is acting like a prism sorting out the different wave lengths

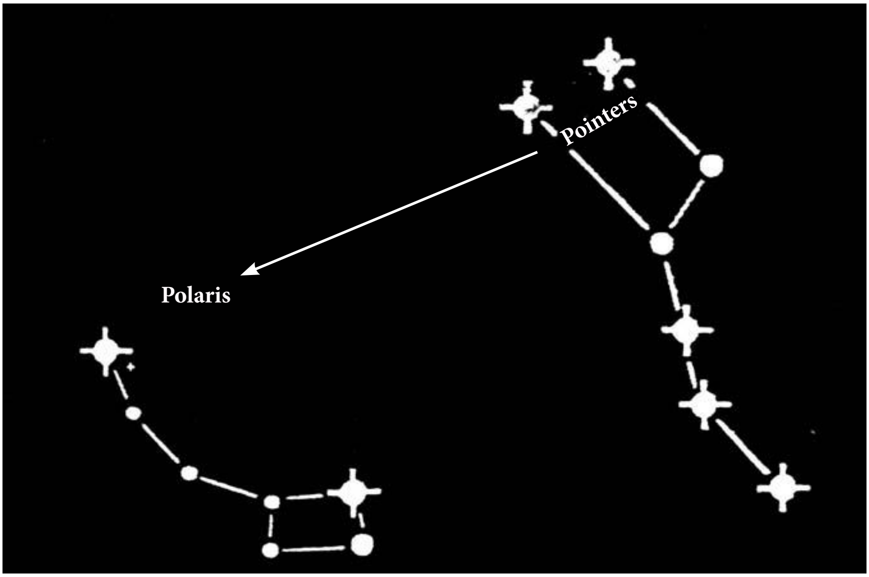


Fig. 7. Stars on the end of the Big Dipper point toward the North Star, Polaris. The handle of the Little Dipper ends at the North Star.

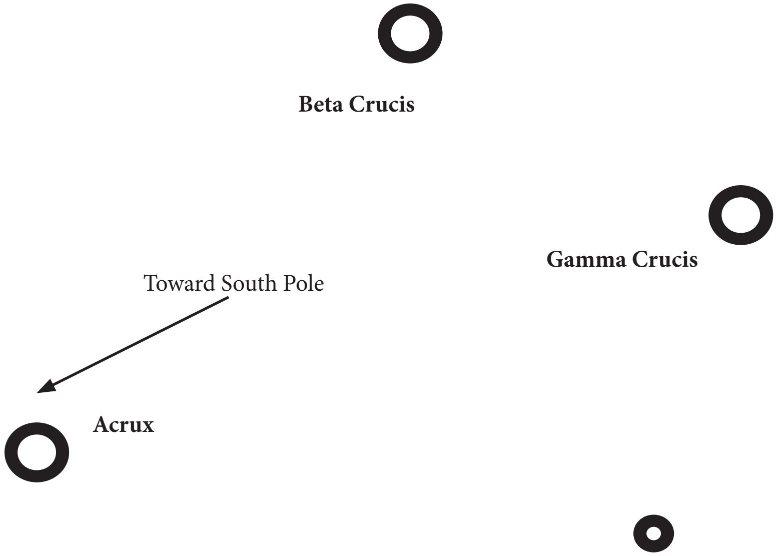


Fig. 8. The Southern Cross points in the general direction of the South Pole; however, there is no major star with a geographic position over the Pole as there is in the North Hemisphere.

of color, all of which occur in rapid succession. Somehow it's the green that predominates, though there have been some rare sightings of other parts of the spectrum. If seen at all at higher latitudes, the flash may last somewhat longer since the Sun sets at a lower angle.

Fig. 9. Aurora Borealis as seen from Ogonquit, Maine, August 12, 1919. Copied from painting by Howard Russell Butler. Courtesy of the American Museum of Natural History.

Chapter XVIII. Pollution[1]

When you see plastic trash floating by or you sail through an oil slick, you realize that the old adage the "solution to pollution is dilution" does not always apply, even on the high seas.

You might hope, with the worldwide ban on overboard disposal of plastic trash, that we might soon see an end to much of this; however, since plastics are extremely slow to disintegrate, there is an unfortunate persistent accumulation[2] (Fig. 1 and 2). And the ban doesn't provide for accidental inputs such as lost fishing gear.

Oil pollution is quite a different story. Given time, most of the oil will evaporate or disintegrate but not before doing considerable irreversible damage. Hopefully, oil pollution related to shipping will be less of a problem in the future since, instead of loading ballast water in emptied oil cargo tanks, regulations now call for providing separate container space for the purpose. This, of course, means that ballast pumped overboard will be relatively clean. Also, with double–hull construction required for new large tankers, there should be far less oil damage from shipwrecks. Yet we still face the problem of blowouts and leaks at drilling sites. Also, oil washing off the land, particularly from streets and parking lots, is

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1 Numerous regulations apply relative to the pollutants discussed in this chapter and these not only differ regionally but are often changing. Accordingly, it is necessary to refer to such rulings in rather general terms. For many of the existing regulations, you might refer to the London Dumping Convention, its annexes and the updating thereof.

2 When glass bottles were the norm, before the advent of ubiquitous plastic containers, there was considerable broken glass to be found washed ashore. I collected choice pieces while beachcombing.

Fig. 1. Trash, mostly plastic, on the windward shore of Bonaire in the Caribbean. Throwing trash overboard has been banned for some time yet, from this accumulation, you can see how it persists. Photo by Paul Joyce.

another continuing problem. With our energy needs linked to oil we will continue to face some unfortunate consequences (Fig. 3, 4, 5, 6). (Note the addendum to this chapter on The Fate of Oil Spills.)

The plastics, oil, and much else that you see in your travels are but a fraction of the pollutants stressing the marine environment. Most of the toxins that are waste products of our society, (i.e. numerous organochlorines, trace metals, radioactive wastes, etc.), are in a dissolved or colloidal state and much of this input eventually accumulates in the tissues of living organisms and in the sediments. Finally, we should

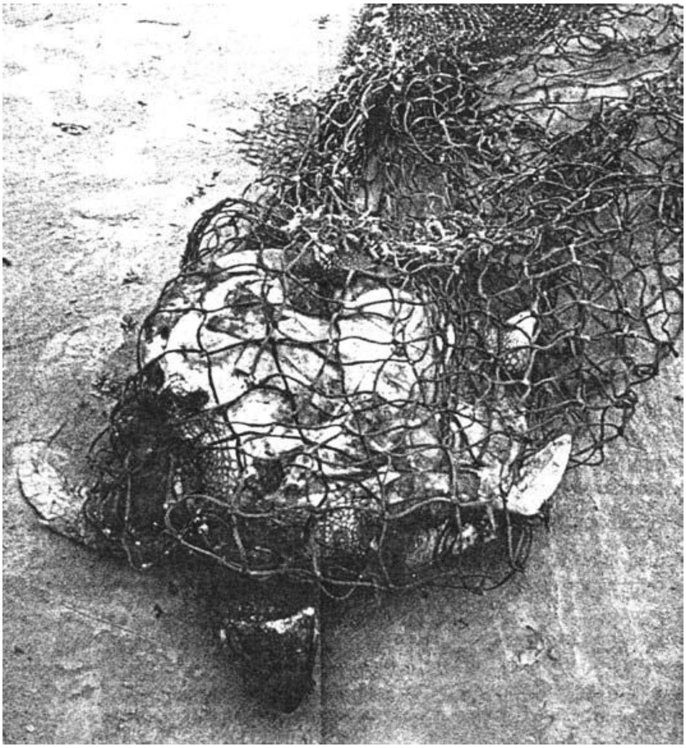

Fig. 2. Turtle entangled in lost fishing gear. Source: National Park Service.

be aware that, since many of these pollutants are airborne, there are substantial inputs from far inland. So, to understand the extent of the pollution problem we must discuss conditions that we cannot see.

Radioactive wastes are high on the list of pollutants that go unnoticed by observers at sea. While there had been some ocean dumping of such wastes in the past, this is now completely banned under the London Dumping Convention. As a consequence of the ban, the many countries generating radioactive waste from power plants or other operations are struggling to find alternate disposal provisions, and I dare say that no one has found a solution that is entirely satisfactory. Though not a major source, we must also recognize that there continues to be some radioactive fallout from nuclear weapons testing.

Unfortunately, particularly when decommissioning, there are no adequate provisions for avoiding some leakage of radioactivity from

Fig. 3. Exxon Valdez wrecked on Bligh Reef 25 miles out of Valdez in March of 1989. Almost 9 million gallons of oil were spilled from large gashes in the hull. Source: NOAA.

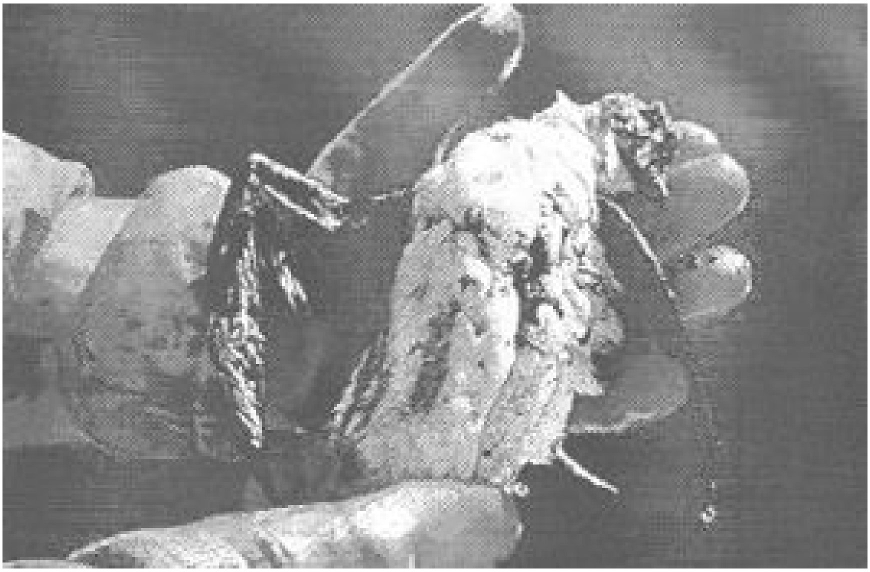

Fig. 4. Murrelet, one of many casualties of the Exxon Valdez Oil Spill. Source: Alaska State Archive.

Fig. 5. Oil drilling platform Harvest operating 11 km (~7 mi) off the coast of California in 200 m (650 ft) of water. Source: Minerals Management Service, U.S. Interior Department. (As noted in footnote 3 of Chapter II, drilling had been banned for sometime from all sites such as this though they could pump from oil straits that had already been reached.)

Fig. 6. Blowout at the IXTOC 1 exploratory well off Ciudad del Carmen, Mexico, on June 3, 1979. Before being brought under control some 140 million gallons of oil had been spilled. This is thought to be one of the largest spills of all time. Source: NOAA.

nuclear-powered vessels. The former Soviet Union has been experiencing serious leakage problems while decommissioning naval vessels, including submarines, laid up in ports in the Arctic and Northwest Pacific. The migration of fish populations contaminated from such leakage spreads the problem over a very wide area.

For other pollutants, we must also consider the source, the nature and quantity, the pathways into the environment, and the ultimate history. To cover the subject would take volumes, yet there are some highlights and generalizations that we can consider. Noteworthy is a treaty to forbid any use of the persistent organic chemicals known as POPS which are nicknamed the "dirty dozen" and which include PCBs, certain insecticides, and the very toxic dioxins and furans. A partial exception under this treaty permits the use of DDT in developing countries where there is a need to combat malaria by killing mosquitoes and to control other insects that transmit disease.[3]

Not infrequently toxins that enter the environment in very limited amounts are not serious pollutants until they become concentrated in foods that are eaten. Thus with successive steps up the food chain, the amount in the surrounding waters may become concentrated 10,000 to 100,000 times and even more in a process referred to as bioaccumulation.

A well-known example is the low level of mercury in the environment which is commonly found in toxic concentrations in the flesh of many higher predators such as sharks, tunas, swordfish, groupers, and halibut. (Mercury concentrations have also been found in whales and dolphins and are of concern where cetaceans are eaten.) Eating contaminated fish in more than limited quantities can result in neurological damage, kidney, liver, and heart problems, and much more. The risk is especially serious in pregnant women, as it may result in permanent IQ loss in their children.

Though a considerable amount of the mercury has been accumulating from natural sources over the years, it should be possible to keep the mercury level quite low through restrictions on our inputs, largely from coal-fired power plants and miscellaneous manufacturing. Increasingly, public health officials are advising people to limit their consumption of toxic fish, but regulations in the United States and in other countries are not sufficient to stem the tide of mercury inputs, particularly the emissions of the power plants.

Another troublesome example of bioaccumulation is ciguatera

3 Due to toxic effects on humans, any use of DDT has been curtailed somewhat.

Consumer Level	DDT Concentration in Parts per Million (PPM)
Fallout and Phytoplankton uptake	0.000002
Primary Consumers (Zooplankton)	0.04
Small fishes feeding on zooplankton	0.5
Predatory Consumers (Larger Fishes)	1.5
Seabirds	20

BIOACCUMULATION

Fig. 7. Example of how DDT may bioaccumulate through the food chain.

poisoning in fish. The effect, should you eat such fish, is highly varied and includes extreme nausea and muscular paralysis. It is attributed to certain dinoflagellates present on seaweeds growing in coral reef areas. After herbivorous fish eat seaweeds coated with the toxic dinoflagellates, the poison is concentrated up the food chain to predatory fish. This tends to be a localized problem which comes and goes, often being associated with both natural and human disruptions of coral reef environments.

Where there is even a suspicion of ciguatera, you should avoid eating predatory fishes from reef locales. Natives have been known to test fish by first feeding them to cats. Reasonable, perhaps, if a stray cat rather than a pet is used and if the test animal does not regurgitate the sample. Obviously, where the presence of ciguatera is suspected, it is a deterrent to developing fisheries. If fish being marketed are suspect, there is no sure way to avoid the problem, though it may help to indicate where the catch came from.

In addition to bioaccumulation through steps up the food chain, there are the toxic effects resulting where organisms directly concentrate metals that might otherwise be quite harmless. Shellfish, including such favorites as oysters, clams, scallops, and mussels, may concentrate certain metals as much as 100,000 times the levels found in the surroundings. The problem of lead in the environment illustrates this for, although the amount present may be very low, it can become highly concentrated in the tissues of shellfish and can be very damaging to the brain and nervous system in general. This obviously has nothing to do with observations on the high seas but has a great deal to do with what you may gather and eat when you are ashore.

In your travels, you may have encountered an occasional bloom of phytoplankton as referred to in Chapter IX. Different species of dinoflagellates are commonly involved in these blooms, with many being quite toxic when concentrated. As described in Chapter IX, these blooms are often lumped under the heading of red tides though, depending on the species of plankton involved, the water may appear more green, brown, yellow, or even white. While levels of the basic nutrients, (i.e., nitrogen and phosphorus), are generally high where troublesome blooms (also known as Harmful Algal Blooms, or HABs) occur and may be part of the cause, it is often difficult to determine what unique inputs might be triggering these effects (Fig. 8). There is a growing concern that the

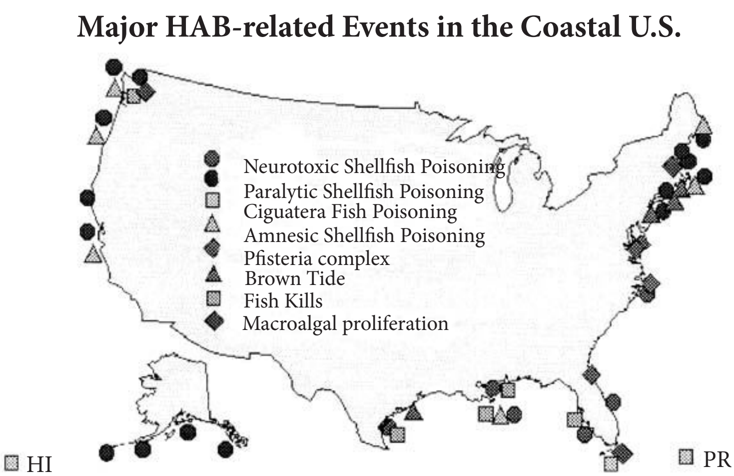

Fig. 8. Harmful algal blooms in the coastal regions of the United States. Many of the effects occur less frequently and with less regularity than this map might suggest. Source: National Office of Marine Biotoxins and Harmful Algal Blooms, Woods Hole Oceanographic Institution.

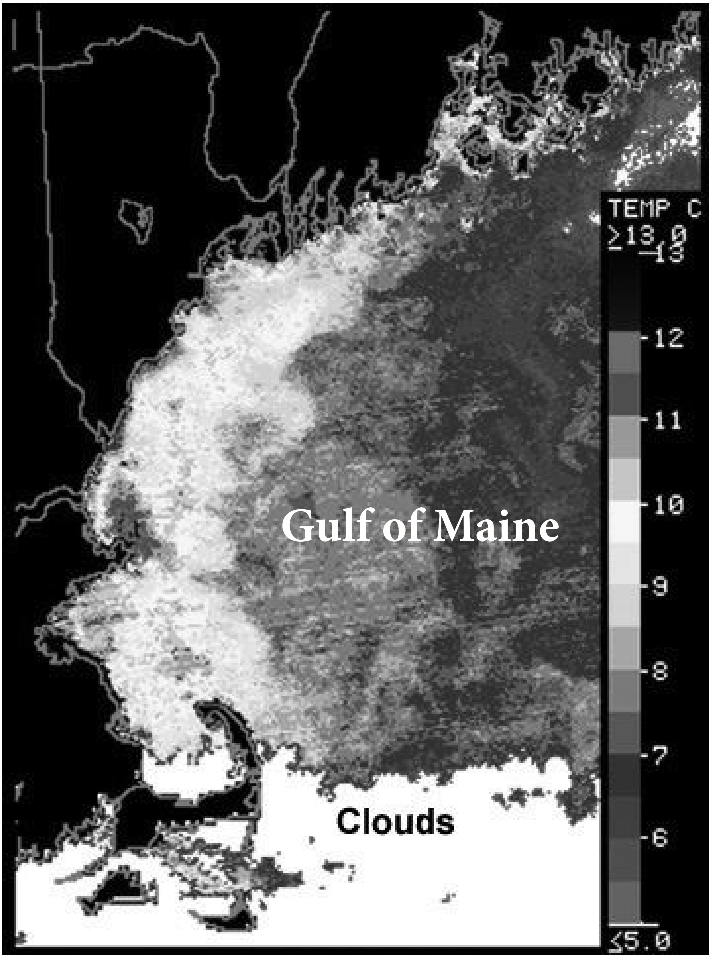

Fig. 9. A bloom of toxic dinoflagellates along the coast of the Gulf of Maine. (As the color is lost in this black and white reproduction, the bloom appears white along the coast). This is the source of paralytic shellfish poisoning (PSP), a neurotoxin acquired from eating shellfish, primarily mussels, when these plankton concentrations occur. Source: NOAA Coastwatch.

apparent increase in red tides is indicative of a cumulative increase in environmental pollution. Finally, there is no sure answer to the basic question: Are there more such blooms today than in the past or are we simply noticing them more? It is probably a bit of each.

One very familiar example of the effect of a phytoplankton concentration occurs almost every summer in the Gulf of Maine and involves a dinoflagellate that causes paralytic shellfish poisoning (Fig. 9). The shellfish that filter seawater and concentrate the plankton remain in good condition. However, you can experience nerve poisoning and associated paralysis if you eat seafood, particularly mussels, that contain very high concentrations. Warnings are commonly posted when these concentrations of phytoplankton occur.

Considering the problems associated with toxic blooms, those resulting from bioaccumulation, and the concentration of toxic metals, you can appreciate that public health advisories, like the warnings provided in the Gulf of Maine, are highly desirable. Unfortunately, marine ecosystems are so complex that it is often hard to predict hazardous conditions before the first signs of any given problem have been detected.

Finally, you should be aware that some toxins accumulating in the environment come from natural sources and have nothing to do with human activities. As mentioned above, some of the mercury present in the oceans is derived from natural sources. In the Gulf of Mexico, it has been observed that some of the oil on the surface comes from the natural seepage of fossil oil from the sediments.

From the foregoing accounts, you can sense that, in general, pollution is more of a problem in coastal waters than well offshore. The contrast would be even greater if we were to compare conditions in estuarine and inland waters with the cleaner waters offshore. Thus, we realize that although for some toxic pollutants their presence, even in trace amounts, may be of concern, dilution can usually be very effective in abating pollution.

When it comes to dealing with domestic wastes, which we have not discussed thus far and which are primarily toilet effluents and gray water from laundering, dishwashing, and general cleaning activities, dilution is very important but may not be sufficient. Thus, for enclosed areas we commonly rely on sewage treatment plants that, after settling out the objectionable organic matter, typically discharge water that is relatively clean but has a high nutrient content. This nutrient loading is often augmented due to the run-off of fertilizers from bordering lands and the seepage from septic tanks. When, one way or another, nutrients become excessive inshore, intensive algal growths may occur, and decay and oxygen depletion may follow. In many areas, to avoid adding to this problem, vessels of all sizes are required to retain domestic wastes, at least from their toilets, in holding tanks. Such holdings may be pumped out at a discharge station or discharged overboard once clear of limited surroundings.

Contrary to the usual favorable dilution in open waters, there are areas off the coast where no amount of dilution seems sufficient. One such area lies off the delta of the Mississippi River where there is a recurrent oxygen-depleted dead zone generally attributed to nutrient loading due to the fertilizers from agriculture in the enormous watershed involved.

A dead zone occuring close to the Oregon coast recently may be attributed to increased phytoplankton and subsequent decay in the wake of stronger upwelling. This is being compared to dead zones linked to the Peru or Humboldt (off West Coast and South America) and Benguela (off southwest Africa) Current systems. Actually there has been a world-wide increase in similar dead zones.

Finally, there is a growing concern that cruise ships carrying thousands of passengers may pose problems due to disposal at sea. In ports where adequate provisions exist, the domestic wastes may be pumped out from the holding tanks of these ships. And discharge while underway in open waters is generally allowed, although Annex 4 of the Marpol Convention specifically prohibits such disposal in some designated areas. With the increasing number of cruise ships making short runs from port to port, there may be a need for more such restrictions.

Now we come to global warming, the most worrisome problem of all. Perhaps you are aware of this if you recall or have been told of the colder winters of the recent past. However, since the temperature fluctuates with changes in the weather, trying to quantify and interpret the warming trend is greatly complicated. We know that warming is taking place naturally, but the realization that this is being appreciably accelerated by human activity is very disturbing. Such increased warming has been verified by an Intergovernmental Panel on Climate Change (IPCC) sponsored by the United Nations and representing the consensus of hundreds of participating scientists.

The major cause of this rise in temperature is the carbon dioxide (CO_2) that humans are discharging into the atmosphere through the combustion of fossil fuels for our endless energy needs, (i.e. automotive power, electricity, and on and on) (Fig. 10).

Methane, produced by decay processes on Earth and in the sea, is another gas involved and the amount in the atmosphere is expected to be

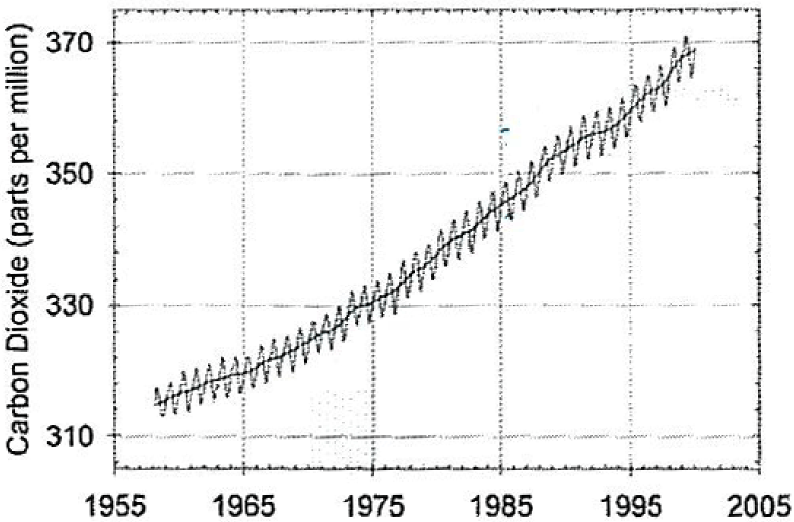

Fig. 10. The increase in atmospheric carbon dioxide concentrations measured at NOAA's Observatory in Mauna, Hawaii, since 1958. (Data prior to 1974 are from the Scripps Institute of Oceanography.) The oscillations reflect the diurnal differences in CO_2 uptake through photosynthesis. Source: Climate monitoring Diagnostic Laboratory.

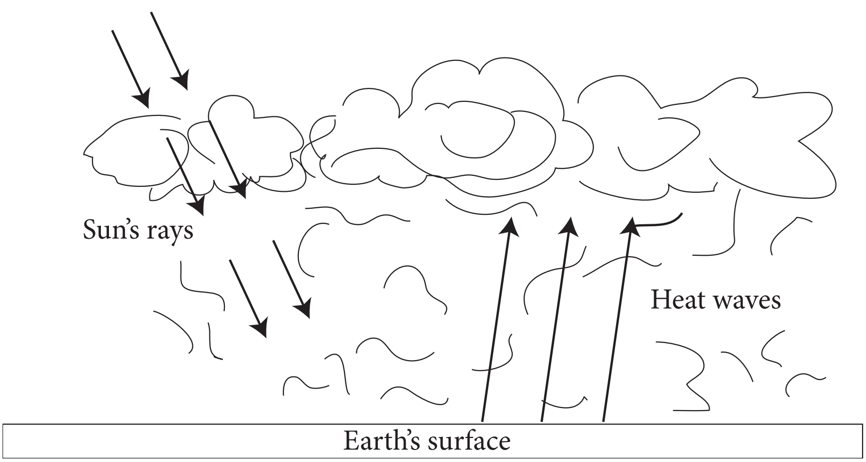

Fig. 11. The "greenhouse effect."

increasing[4]. Chlorofluorocarbons such as freon used in air conditioning, refrigeration, and as an aerosol propellant, also contribute to pollution, though their use is now banned by many countries. The accumulation of these gases creates conditions which allow the short heat waves of the sun to penetrate whereas, after this radiation is converted to longer heat waves over the surface of the Planet, they tend to be absorbed in the overlying atmosphere. As this resembles the function of a greenhouse, where the long heat waves cannot readily pass outward through the glass roof, it is commonly referred to as the greenhouse effect (Fig. 11).

While the IPCC is unequivocal in pointing to the role of human activities as a major cause of accelerated global warming, projections as to the rate of change remain rather vague. A 2006 revised estimate from the IPCC predicts a temperature change of 1.9° to 4.4° C (3.5° to 8° F) by the end of the present century.

Since the oceans cover 70% of the Earth's surface, they play a major role with respect to the warming. Accordingly, much of our oceanographic research today is focused on the uptake, deposition, and recycling of CO_2 between the atmosphere and the oceans. Some attention is directed to the possibility of shifting the cycle to increase the uptake by the photosynthesis of phytoplankton and the retention in the marine environment of carbon dioxide and its derivatives, such as organic carbon and calcium bicarbonate. On the other hand, any increases of carbon dioxide in the water column tends to make it more acidic and less favorable for such precipitation.

In Chapter IX we have already mentioned one technique that, off hand, seemed to have the potential of increasing the uptake of carbon dioxide from the atmosphere. This was to add iron to ocean areas where, as a trace element, this might greatly increase the photosynthesis of the phytoplankton and concurrently the uptake of CO_2. As noted, experiments at sea indicate that the concept has real potential; however, we need to know a great deal more about unforeseen consequences before tinkering with the natural chemistry of the world's oceans. Caution in this regard is worth repeating!

The ultimate effects of global warming are difficult for any of us to anticipate. Existing regimes of precipitation and evaporation will be altered. Also, with melting from such sources as the Greenland ice cap plus the ice bound on the Antarctic Continent, in Patagonia, and in

4 A recent study suggests that green vegetation may also release considerable methane.

the glaciers of Alaska, the sea level will rise appreciably. The simple fact that water expands as it becomes warmer will also add to the rise in the elevation of sea. Overall, the rise may range from ~20 to 60 cm (7 to 23 inches); moreover, recent observations of melting that may develop under the glaciers suggest that run-off and accompanying rise in sea level may increase by a great deal more.

A higher sea level will obviously do a great deal of damage to sea ports, beach erosion will increase, shorelines will retreat, saltwater will invade existing freshwater aquifers, and the possibility of storm surges will increase. A rise in sea level will also inundate a number of small, populated oceanic islands and vast areas of low-lying countries such as Bangladesh. In the Netherlands, where there is considerable low-land protected by dikes and there is a continuing need to prevent flooding in areas such as the major port at Rotterdam, projects to protect these areas are well underway.

Especially worrisome, is the possibility that ocean circulation patterns may change, perhaps drastically. There is the possibility that due to warming and increased rainfall in the higher latitudes, the salinity of subarctic waters might be reduced to the point that they no longer sink and draw a major portion of the North Atlantic Drift to the north as described in Chapter VI. If this happens, the climate of Western Europe might become colder. Trying to determine whether or not this is at all imminent is the focus of many on-going oceanographic observations.

While there is talk of a substantial shift of tropical conditions toward the Poles, we have only the vaguest impressions as to how warming will effect the flora and fauna and the associated ecosystems. Interactions may break down between organisms with life history patterns synchronized on the basis of present temperatures. However, we might hope that some shifts toward the Poles will occur with only limited losses. For example, in the North Sea, where there is some evidence of a general northward shift of commercial fish populations, I have heard that the fishing effort has simply been moving more to the north. On the other hand, we must wonder about the fate of populations which require certain features of cold environments that may no longer be available. Such is the plight of the Polar Bears which roam the Arctic and may starve from the scarcity of suitable ice platforms from which to prey on seals and fish.

Actually, we are finding that the effects of global warming tend to be disaproportionately greater in the high latitiudes and several nations have regarded 2007-2008 as an International Polar Year emphasizing cooperative scientific research.[5] At the same time, from explorations of the Arctic sea floor Russia has made a claim, yet to be reviewed, that its continental shelf extends under much of the Arctic Sea.[6]

All this is not to imply that life in the Tropics is not without considerable impact from global warming. One concern is the realization that the bleaching of corals, as discussed in Chapter XVI, is an early and ominous sign of adverse warming effects. Imagine our tropical seas without the luxurious crests of fringing and barrier reefs.

In essence, the likely adverse effects of global warning, which I have only begun to touch upon, are very disturbing. Yet, in spite of the overwhelming consensus of those in the best position to assess what is happening, it is proving difficult to obtain an international consensus in support of actions that might lessen the impact. Thus far, the United States has not agreed to the practices of many other nations that are adopting mitigating measures under an accord, subject to renewal, known as the Kyoto Protocol.

Actually, the Sun's rays are of concern not only relative to global warming but they may also bring about more direct effects, particularly to the extent that rays in the ultraviolet range penetrate to the Earth's surface. A certain amount of ozone is needed in the upper atmosphere as a partial shield limiting this penetration but this layer has become thinner of late. In the extreme, thinning has resulted in "ozone holes" in the Polar regions. Special warnings are issued in Australia to advise the public of the added hazard due to ozone thinning over the continent.[7]

This ozone loss is largely the result of an accumulation of chlorofluorocarbons (CFC), mentioned above as one of the lesser contributions to global warming. An international agreement, essentially banning the use of CFCs and known as the Montreal Protocol, addresses this problem. We are now seeing signs of ozone recovery and can

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5 From the high rate of melting in the Arctic, some speculate that the Arctic Ocean may be ice-free in the summer as early as 2030; furthermore, the Northwest Passage might become the regular trade route searched for without success by several early explorers.

6 This prompts other nations to focus on acquiring information to match the Russian claim. It is reported that Norway has also submitted a claim and their are countries making claims elsewhere, not just in the Arctic. No doubt approval of any such claim will be delayed, at least not until neighboring nations' interests have been reviewed.

7 While ozone serves as a desirable shield in the atmosphere, quantities that may occur with pollution conditions near the Earth's surface may cause breathing problems.

hope that the penetration of the Sun's harmful rays will be substantially reversed.

Skin cancer and eye damage are the health consequences of this penetration, and since even in the best of circumstances the ozone shield has never been altogether effective in protecting one from the Sun's rays, you should always avoid exposing your skin for extended periods. Considering the glare off the sea surface, you should add protection for your eyes.

All exposure to the sun has a unique, long-range effect wherein any damage to the skin is sustained through the years and may take effect later in life. Accordingly, feeling relieved when excessive sun damage seems to have passed is an illusion since the residual harm may show up when skin cancers develop later in life.

It is important to realize also that excessive UV penetration not only affects humans but may have adverse effects on life on Earth in general. Possibly the increase of the ultraviolet will have an adverse impact on photosynthesis, upsetting the normal ecosystem regimes in the sea and on the land.

Finally, I must mention dimethyl sulfide(DMS) which is produced by phytoplankton and enters the overlying air at the sea surface. At sea you may never notice DMS; however, on approaching the seashore, it may be quite apparent along with the salty tang in the air. Since DMS is a natural output I don't think of it as a pollutant; however, in the atmosphere it can have the effect of increased cloud formations, reduced light penetration, and some acid rain, all being related to sulfate accumulation and often augmented by airborne sulfate from land sources.

Overall, the impact of pollution and pollution-related activities has been such that no oceans are free of some unfavorable conditions. The western Pacific off China is one of the most heavily affected areas.

Addendum: The Fate of Oil Spills

Though highly publicized, accidental spills from tanker wrecks actually account for only about 20% of the crude oil annually discharged into the oceans. Most of the remainder is the result of routine operations including the discharge of ballast water so common in the past.

Just how any given crude oil entering the environment decomposes depends on its specific composition, yet some generalizations apply. Though they may cause considerable immediate environmental damage, the less dense (lighter) components of spilled oil are more volatile and tend to evaporate into the atmosphere. The heavier components tend to form a sticky oil and water combination called mousse. If absorbed onto solid particles this may sink to the bottom or wash up on shore. Also, on mixing with the sediments and the beach sands, this may form tar balls or, worse yet, a continuous tar-dominated mass. At this stage the oil which remains from an accident has been degraded into simpler and usually less harmful substances due largely to the action of sunlight or bacteria or both but not before considerable harm has been done.

All told, the cumulative adverse effects of oil include direct contact as illustrated in pictures of oil-soaked birds, ingestion and the resulting poisoning, and finally, a general degradation of affected habitats which may be the greatest harm in the long run.

The common methods for immediately addressing an oil spill include containment and recovery, dispersal, biological remediation, and burning. Containment and recovery is to be preferred if the equipment, the operating personnel, and the overall circumstances allow. General dispersal, by some chemical means such as adding a dispersant, is not optimal for it is likely to result in just what the name implies, i.e. causing the problem to be spread over a wider area. Introducing fertilizer for the growth of naturally occurring bacteria that attack the oil and may encourage biodegradation can be quite successful. Burning is not desirable as it adds considerable carbon dioxide into the atmosphere. Obviously, accidental burning cannot always be avoided.

Chapter XIX.
Oceanography from the Beach

Obviously you will be ashore more than out at sea, so I suggest that you delve into the many interesting aspects of oceanography that you can see where the sea meets the shoreline. While observing from the beach you might want to refer back to earlier chapters, particularly:

Chapter II	**From the Coast to the Depths of the High Seas**
Chapter III	**Wind-Generated Waves and Breakers**
Chapter IV	**More on waves**
Chapter VII	**Tides and Tidal Currents**
Chapter XIII	**Turtles of the High Seas**
Chapter XV	**Seabirds**
Chapter XVIII	**Pollution**

Imagine that you are standing on a well developed beach. What is the sand beneath your feet? Is it mostly tiny grains of quartz and feldspar derived from the weathering of granitic rock? Or is it very similar, perhaps derived from basalt rocks. You might be inclined to think of these as typical sands for they are so common in resort areas or, to put it another way, resorts are so often developed where this kind of sand occurs. Such sand is very light in color but not white; nor is it a light yellow. I'll beg the question and say it's simply sand-colored.

There are many other beach materials the world over. Some beaches where the source may be volcanic rock may be dark gray, almost black. If you are on such a beach, look about to see if you can identify the likely sources. In the tropics the sand may be white, even "blindingly" so, as the sunlight is reflected off the accumulation of the crushed calcium carbonate remains of life in the region (Fig. 1). Can you identify any of the pulverized remains, such as the blades of the calcareous alga, *Halimeda*, or crushed bits of coral and shell, that make up the beach? Use a hand lens.

In response to the sorting effect of wave action you may see areas where the coarser grains of sand remain while the finer particles have been washed away. In the extreme, an area of the beach may consist of pebbles and small rounded rocks. Or, you could be on a beach that doesn't seem sandy at all. For instance, there are beaches consisting largely of cobble or of small flat stones referred to as shingle (Fig. 2). Needless to say, beaches may be of mixed composition and I have not, by any means, exhausted all the possibilities you may experience.

When the winds are moderate and there are no crashing breakers, beaches are usually treated kindly. Sculptured by the incoming flow of water, such a beach has a gradual slope with a tendency for an accumulation of sand, called a berm, to be deposited at the high landward elevation (Fig. 3). Some of the flow back to the water's edge seeps into the sand and returns beneath the surface. Where this slope is very slight

Fig. 1. White sand beach at Panope, Caroline Islands, South Pacific. Photo by Henry S. Parker.

Fig. 2. A cobble beach. Source: NOAA.

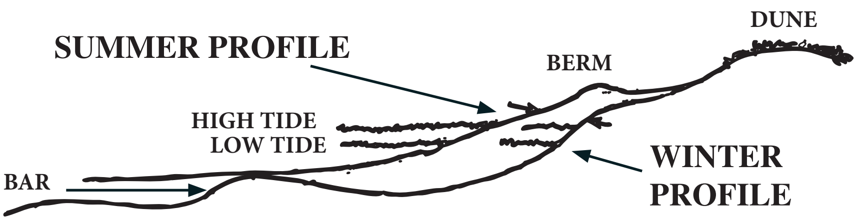

Fig. 3. Summer and winter beach profiles.

Fig. 4. Ripples in the sand at the water's edge. Photo by David Griffiths.

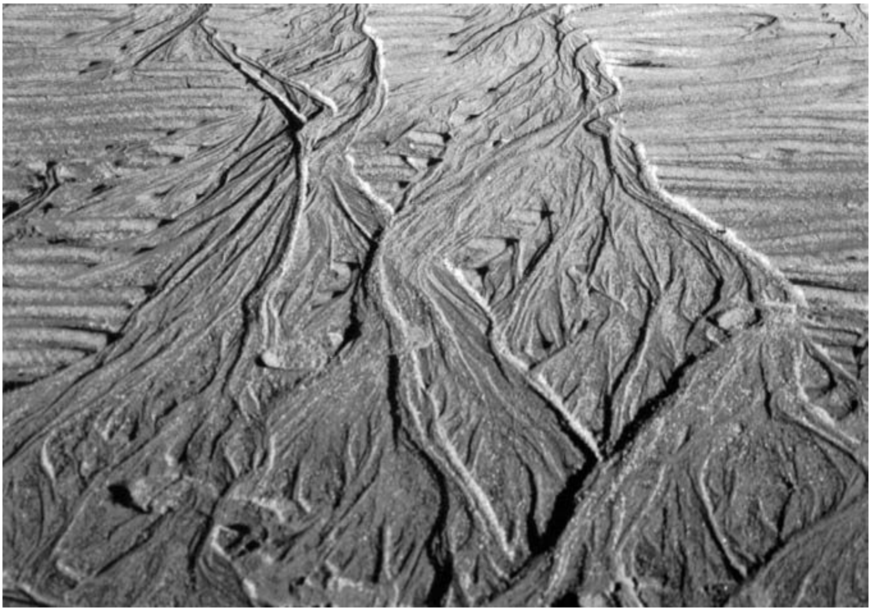

Fig. 5. Other patterns near the water's edge. Photo by David Griffiths.

you may see some unique effects next to the water. There may be small ripples on the surface of the sand where the flow alternately stirs and deposits the sand grains or, if the surface is unusually smooth, it may have a glassy appearance (Fig. 4, 5). Just beyond the shoreline there may be a shallow trough and beyond that a shallow bar. Under such moderate wave action a beach is said to have a summer profile, not because it develops seasonally but because storms are less frequent during the warmer weather and spilling breakers, with a long run-up onto the beach, tend to prevail.

On the other hand, during stormy weather, breakers may tend to cut into the beach as they plunge ashore tending to wash away any berm that has formed and to transport sand offshore. Again the so-called winter profile that results is not necessarily seasonal though the effect may be more common in winter when storms are more frequent. Not only is the slope of the winter profile relatively steep but, due to the scouring action as incoming waves transport considerable sand parallel to the shoreline, the trough that develops just beyond the water's edge may be deepened. Also, the bar that builds up just beyond the trough may be well developed. Such wave action may result in a series of bars at progressive distances from the shoreline.

As you look out at the breakers ask yourself how these relate to the beach profiles just discussed. Due to the offshore bars, the waves may be breaking at some distance from the shoreline. You will also see that, even on a lee shore, the waves are always directed toward the beach. This, of course, is due to refraction. Inevitably, as breaking waves come ashore at a slight angle, some flow develops along the beach until it breaks out as a rip current. (Refraction and rip currents were first discussed and illustrated in Chapter III dealing with wind-generated waves.)

Looking along the beach you may also sense the longshore drift of the sand. For example, wherever there is a jetty you will inevitably see sand piled up on one side and scoured away behind (Fig. 6). Drifting sand may also result in a cuspate shoreline (Fig. 7). Where you see what you might call giant cusps, such as those along the coast of North Carolina as shown in the illustration of Pamlico and Albermerle Sounds in the next chapter, it appears that large scale eddies of the ocean circulation along the coast may contribute to this. Actually, while the bar along the North Carolina coast from Nags Head to the south of Cape Lookout appears quite substantial and considerable housing and even small towns are

Fig. 6. Longshore accumulation of drifting sand. Note the man standing on the end of the jetty and the buildup of sand on the upcurrent side to his right. Photo by Bob Holman.

Fig. 7. A cuspate shoreline off Flax Pond along the North Shore of Long Island Sound. Source: National Ocean Survey.

Fig. 8. Rows of beach wrack on a beach in the Bahamas.

located there, it is nothing more than a giant sand formation built up by the currents and modified by the winds.

Finally, you may find that storm surges and tsunamis of the past have had amazing impacts along the shore. For example, it is not unusual to find boulders cast high above the highest tide lines.

Do some beachcombing. The messier the beach, the more there is to see. Most everything washed up has a story to tell. No doubt you will be on the lookout for shells but first consider the beach wrack often occurring in somewhat parallel lines along the length of the beach (Fig. 8).

High on the beach, even amongst the bordering terrestrial vegetation, there may be an accumulation of flotsam, including bottom vegetation defoliated and uprooted and washed ashore. While this accumulation is indicative of the extremes of high water and storm surges, the most pronounced line of wrack is likely to be a bit lower on the beach where repeated tides have built up another accumulation. There may be one or two more lines, perhaps one for recent high tides and one that is nothing more than a faint row near the water's edge.

Often the beach wrack consists largely of drifting grasses. Occasionally Kelp washes in (Fig. 9). The latter is the largest form of marine vegetation, being attached to the bottom some distance offshore with each plant having a bottom holdfast, a long stem, and leafy fronds which reach toward and, at low tide, float on the surface. Perhaps a considerable quantity of *Sargassum* has also accumulated on the beach. This is tan in color and has floats that enables it to drift about on the surface of the sea, perhaps from far away. (See the sketch of *Sargussum* in Chapter XI.)

Be sure to spread out some of the accumulated wrack. You will witness a lively scene dominated by Beach Hoppers and a variety of insects.

Fig. 9. My daughter displays a complete frond of kelp that had washed up on the beach. The bottom holdfast is below her right hand; the leaves that float on the surface when the tide is low are below her left hand. Kelp commonly has longer stems extending to depths of 40 feet or more. Photo by David Griffiths.

Some jelly-like forms may have washed ashore and may be semi-intact. In some areas, you may see the Portuguese Man-o-War, or the By-the-Wind-Sailor, perhaps the Moon Jelly and other members of the jellyfish group. Handle with care for it could be that the stinging cells of these remains are still alive and severely irritating. (Again, see the sketches in Chapter XI.)

Foam, looking like soapsuds, may accumulate along the waterline. This is the same as the foam occurring in windrows as mentioned at the end of Chapter IV where it was noted that it is an excess of organic matter from a healthy abundance of phytoplankton.

Neat little leathery, black mermaid's purses, a little over an inch long commonly wash ashore (Fig. 10). If such a purse has not been desiccated and is kept in a suitable aquarium, several small skates, which look just like miniature adults, should hatch out.

Spiral strings of flattened egg cases, each about the size of a quarter and containing a number of baby whelks may have washed up (Fig. 10). At birth they too are perfect miniatures of the adults.

Tiny holes may be seen in the wetted sand. While some may just be the

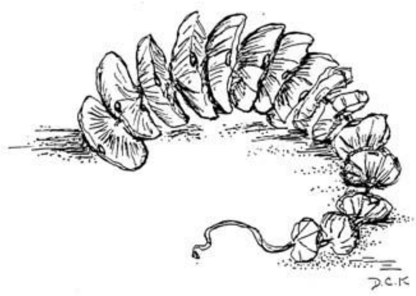

Fig. 10. Whelk egg cases. Drawing by Debbie Kennedy.

result of water seeping down through the sand grains, many may involve inhabitants below. Though much of the life in this environment is too tiny to see, you can sense, from the shorebirds running along and feeding next to the water's edge, that there is an abundance of microscopic food to be had. If you have appropriate tools, try digging to see if you can find larger forms of life. Don't be surprised if some occupants burrow faster than you can dig. Still you may encounter a treasure of clams, sand worms, etc., even a big Geoduck Clam if you are in the right region.

You may run across the molts of various crabs and other animals that have abandoned their chitinous skeletons as they grow and form new skeletons. If Ghost Crabs are present you may have been noticing their tracks running to and from their burrows. Perhaps you have seen the ghosts skittering about (Fig. 11). Some snails also make tracks along the beach. A Hermit Crab may be seen dragging along an abandoned shell which it uses for a home. Larger tracks up the beach and back may tell the story of sea turtles that have lumbered out of the sea during the night to lay and cover their eggs deep in the sand. (See Chapter XIII)

What do you find in the way of seeds washed ashore? Where did they

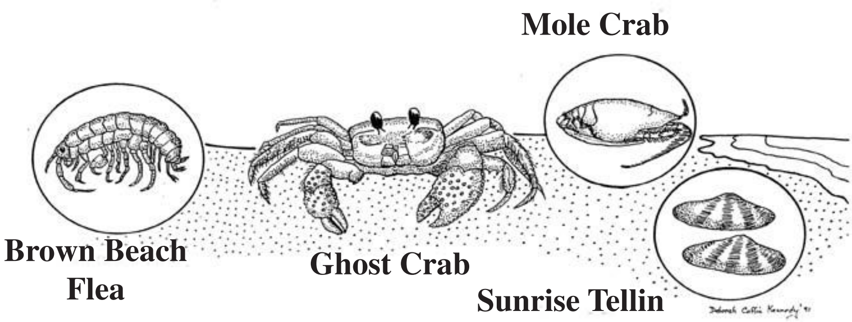

Fig. 11. Common beach fauna. Drawing by Debbie Kennedy.

come from? Are there any remains of upland vegetation littering the beach? This should prompt you to thinking about dispersal in general, contemplating the various ways that plants and animals might populate distant lands (Fig. 12).

If there are logs strewn all over the beach, it's a sign that there are large-scale lumber operations in the hinterlands. More often there are just a few attractive pieces of driftwood scattered about. The occasional big log that has drifted onshore can be worth examining for marine life, including shipworms, barnacles, and algae (Fig. 13). Here we might add a bit of mystery. Suppose you were to find timbers that may have come from a shipwreck. If so, where and when was the wreck? Think of the nearshore conditions that may have caused it.

What bony skeletons do you find washed ashore? Where did these

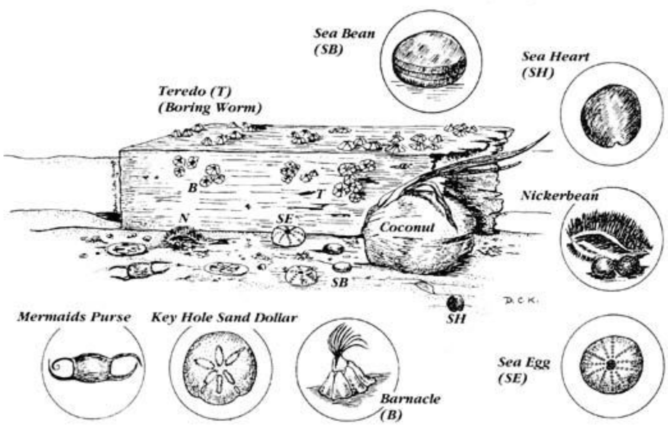

Fig. 12. Timber, various seeds, etc., washed up on the shore. Drawing by Debbie Kennedy.

Sectional portrayal of log penetrated by shipworms. Old tunnels appear in black. One very large shipworm has been teased out to show details, with the rounded end (lower left) consisting of the two shells of this bivalve that are used for boring, and (upper middle) larvae being expelled from one of the siphons. A sea squirt (on the left) is consuming some of the larvae. Also shown, crawling on the surface, are the isopods, Limnoria, which tunnel just below the wood surface. (Drawing courtesy of Douglas Morgan.)

Fig. 13. Log perforated with shipworms. Once ashore, the shipworms would no longer be spawning as shown here.

critters come from? Any thoughts as to the cause of death? Can you tell anything of the creature's life history and food habits? (Hint: Look at the mouth parts.)

Some active burrowers may be seen along the water's edge. Sand Bugs burrow in clean fine sand and, when a wave comes in covering their burrows, they emerge and move higher up. Similarly, colorful little Donax bivalve mollusks get washed up out of their shallow burrows as the waves wash in, then they quickly dig back into the sand, repeating the routine as needed. Where such burrowers of the water's edge happen to be abundant, the action can be fun to watch.

Along many beaches, Horseshoe Crabs may be seen crawling out of the sea on the high tides of the full and new Moon when they are spawning late in the spring or early in the summer (Fig. 14). There may be a male, possibly two, astride the back of each female. The males are smaller and well positioned to fertilize the eggs which are deposited just above the water's edge.

Along the sandy shores of and the Atlantic Coast of Cape May, New Jersey, this spawning activity is so intense in May and June that hundreds, perhaps thousands, of migrating shorebirds, including Red Knots, Sanderlings, Ruddy Turnstones, and Semipalmated Sandpipers, stop over to consume the deposited eggs and thereby replenish their fuel supply en route from the Caribbean and South America to their nesting grounds in the far North.

Because Horseshoe Crabs have remained virtually unchanged for millions of years they are often referred to as living fossils. Due to the copper in their blood, it appears light blue and has properties uniquely useful for medicinal purposes.

Of course, shells in general may be all over the beach. Empty shells, not live ones, are fair game for collectors. If you are looking for Sand Dollars, focus on the water's edge.

Finally we should talk about trash,

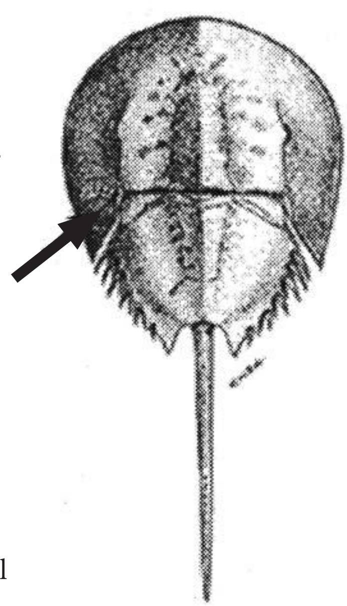

Fig. 14. Horseshoe crab. The arrow points to the location of a tag used for life history research. Source: Maryland Fisheries Resource Office of the U.S. Fish and Wildlife Service.

sometimes very interesting trash. There is all kinds of junk floating on the high seas, ranging from light bulbs to toilet seats, and much of this is bound to wash up on the beach, often high up into the bordering vegetation. In days past , when glass rather than ugly plastic containers were common, I enjoyed collecting pieces of broken glass available in various colors and attractively scuffed up a bit by abrasion from being washed about in the sand. Some of us would make crude glass patterns with our finds. We still get glass balls that have served as floats for fishing gear and have broken loose. These may be found most anywhere in the Pacific. Probably the ultimate in beachcombing is to find a bottle with a message which may have come from the far side of the ocean.

On one occasion a large number of Nike shoes and hiking boots were found washed up along the Northwest Coast of North America. It turns out that a container of these shoes had washed overboard about 2,400 km (1,500 mi) to the west and the drift pattern that brought the Nikes to the coast was just what one would expect on the basis of our knowledge of the circulation in the North Pacific. For the beachcombers, it was such a bonanza that swap meets were held to trade lefts and rights of the same size. A couple of years later a container of bathtub toys, (i.e., rubber ducks, frogs , turtles, etc.), washed overboard at about the same location with many drifting in the North Pacific currents to the shores of Alaska.

You can see why, in addition to the natural history aspect of beachcombing, you can have a lot of fun patrolling the coast. There is even a Beachcombers' and Oceanographers' International Association complete with its *Beachcombers' Alert* newsletter. Membership is worldwide and its web site is www.beachcombers.org/index.html.

Unfortunately, we can't leave the subject of beach conditions without mentioning the all-to-frequent mess involving oil, whether originating from shipwrecks, disasters associated with drilling for oil, ships pumping out their holding tanks, outwash from off the land, or oil from natural seeps. The nature of the oil mixed in the sand depends on the source. Generally, this include lighter components which, though they may be very harmful to marine life and birds, spread rather rapidly and soon evaporate. A black, almost tar-like remnant may persist which, while not as toxic, may remain mixed in the sand. (See the Addendum to the previous chapter on The Fate of Oil Spills.) If you don't watch your step while beachcombing, you may get the tar on your shoes or on your bare feet. An adequate solvent, perhaps kerosene, is needed to remove it.[1]

In conclusion, I must emphasize that, as conditions vary from one setting to another, you can probably add quite a bit to the observations I have suggested. The differences you may observe is part of the fascination of *Oceanography from the Beach.*

1 Moderation is advised in applying anything to your skin.

Chapter XX.
What about Estuaries?

To cover estuaries would call for another book—and a big one at that, for no two estuaries are alike. However, a brief orientation is in order since the chances are you may live on or near an estuary and you are bound to visit many other such areas in your travels.

To begin, what is an estuary? It's a broadened river mouth area or a semi-enclosed arm of the ocean where freshwater from off the land, usually entering from upriver or from multiple tributaries, is mixing with the high salinity water of the ocean as the tide floods and ebbs. The surroundings of an estuary range from steep-sided fjords to low-lying flatlands. The low-lying areas are often bordered by extensive marshes which are generally flooded at high tide and drain considerably with the ebbing tide.

Certain estuarine types are commonly recognized. *Drowned river valleys* are estuaries that exist where the sea has inundated a valley that had been cut into the topography during past glacial periods when the sea level was much lower. The Chesapeake and Delaware Bays are good examples of this type of estuary (Fig. 1). *Bar-built estuaries* are also drowned river valleys but with a bar developing across the mouth and considerable sedimentation behind. The estuary flowing into Niantic Bay in Southern New England is a good example (Fig. 2). *Lagoons*, another estuarine development, may occur where, as is illustrated by Pamlico and Albermarle Sounds along the East Coast of the United States, offshore bars allow for only narrow passes to the open sea (Fig. 3). *Fjords* develop where glaciers have scoured a deep valley behind a shallow entrance or sill connecting to the sea. These are very common along the West Coast

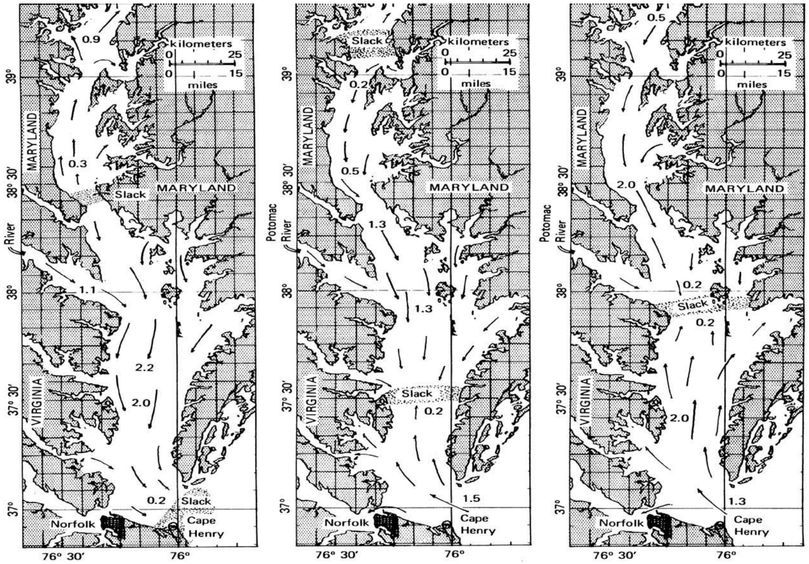

Fig. 1. Chesapeake Bay: An example of a drowned river valley and a well-mixed estuary. Arrows indicate current direction and maximum velocity in km/hr during spring tides. Source: U.S. Naval Oceanographic Office.

Fig. 2. The estuary entering Niantic Bay in Southern New England—an example of a bar built estuary. Source: Northeast Utilities.

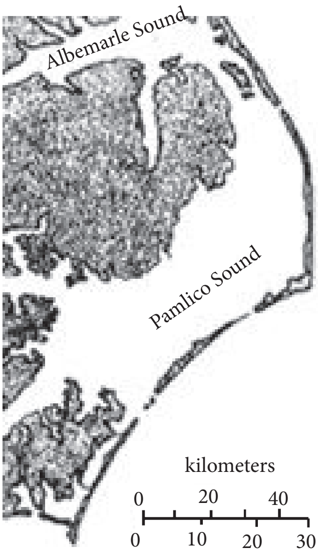

Fig. 3. Lagoon estuaries—Pamlico Sound and Albermarle Sound on the East Coast of the United States. Source: NASA.

Fig. 4. Entrance to Troll Fjord along the Coast of Norway.

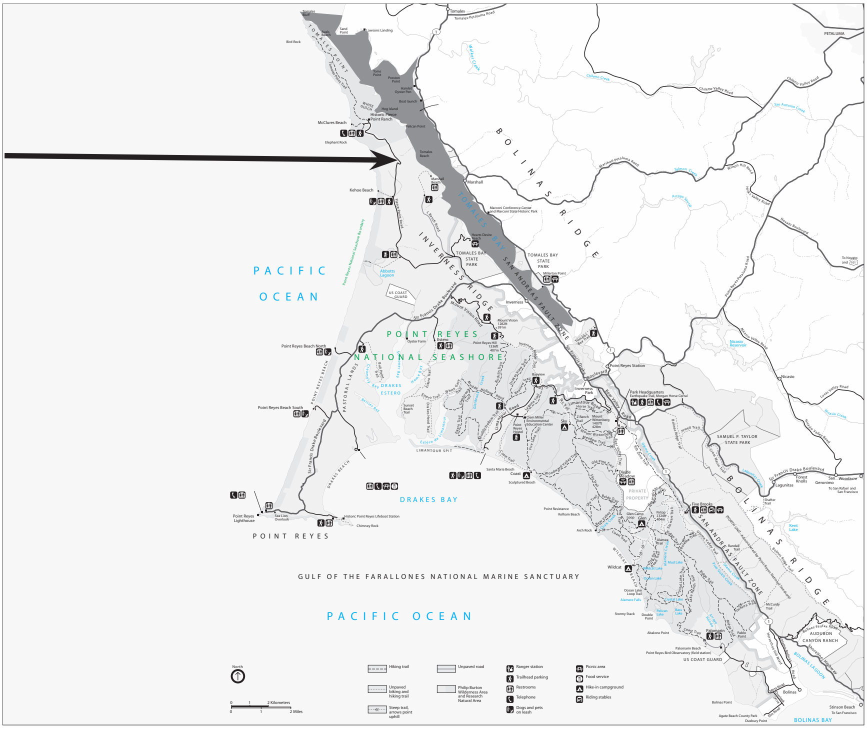

Fig. 5. Tomales Bay—A tectonic estuary situated on the San Andreas fault along the West Coast of the United States. Source: National Park Service, U.S. Department of the Interior.

of Norway (Fig. 4). Occasionally *Tectonic Estuaries* form along the fault lines of earthquakes as in the case of Tomales Bay inundating a stretch of the San Andreas Fault on the West Coast of the United States (Fig. 5).

The circulation in any given estuary is governed largely by the amount of freshwater entering from the tributaries, the strength of the incoming tides, and the size and topography of the estuarine basin. Accordingly, three types of estuarine circulation are widely recognized and, in describing the differences, I find it helpful to begin by referring to the extremes (Fig. 6). On the one hand there are the *salt wedge* estuaries in which the freshwater flow is so strong that the incoming tide enters as a wedge or slanting line along which the mixing takes place. (See figure 6a**)**. Such a wedge may occur in the delta region of the Mississippi River (Fig. 7).

At the other extreme are the *well-mixed estuaries* in which, from the headwaters to the mouth, outflowing freshwater mixes quite thoroughly

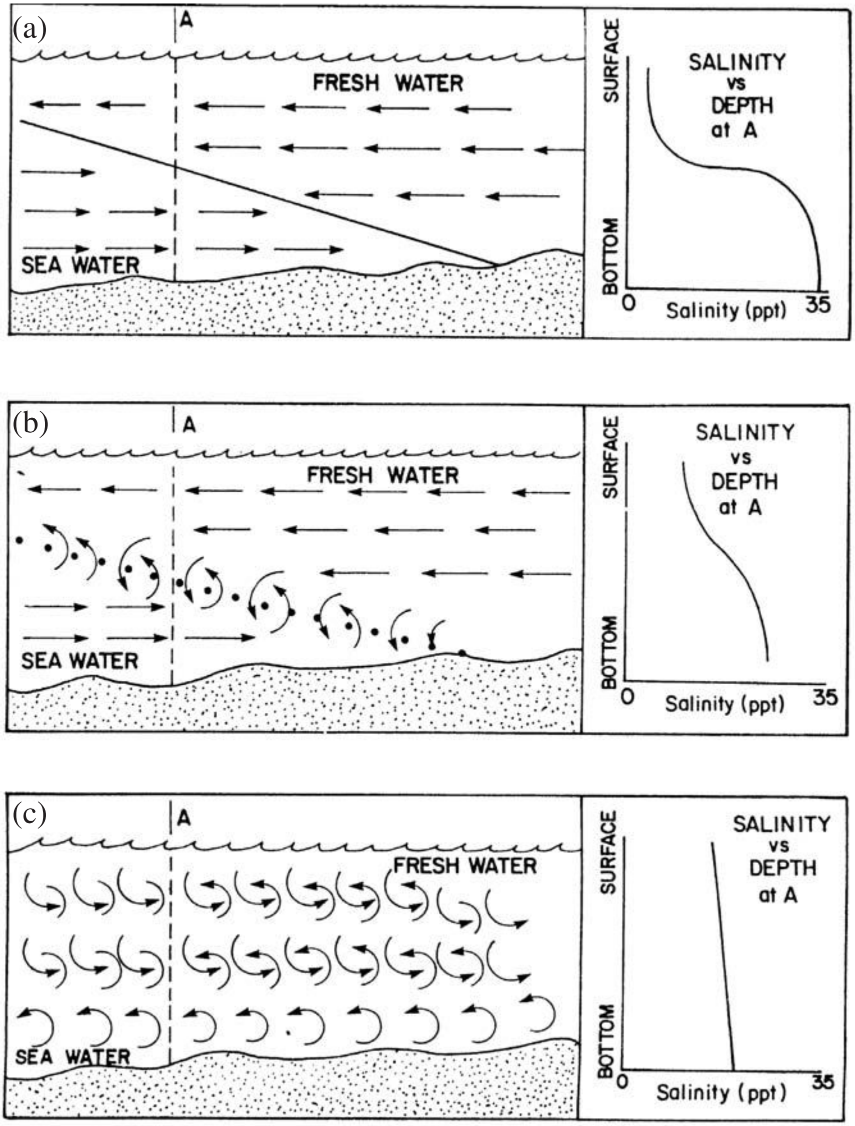

Fig. 6. Estuarine circulation systems: (a) salt wedge estuary, (b) partially-mixed estuary, (c) well-mixed estuary. Source: Weiss, H.M. and M.W. Dorsey, 1979. Investigating the marine Environment. Project Oceanology, Groton, CN.

with the incoming tidal flow. Such mixing is common along many long and relatively shallow systems such as the Chesapeake Bay.

Finally, there are the *partially-mixed estuaries* in which, without complete mixing, the salinity at the surface is still less than that below. (Fig. 6c). Narragansett Bay and is a good example (Fig. 8). If you were to sample the water at the surface and near the bottom most anywhere along the length of such a bay, you would very likely notice an appreciable though not a large difference in salinity. The extent of mixing may vary along the length of any given estuary, usually being greatest toward the mouth.

Conditions within an estuary are closely associated with the inputs from off the land, in other words, from the total terrestrial drainage basin. The fate of such additions largely depends on the circulation patterns just discussed. While there is usually some accumulation of these inputs, within the estuary, in some cases the accumulation may be minimal due to flushing. The effect of added nutrients depends largely on the extent to which they are flushed from the estuary, and extreme nutrient loading results in eutrophication—a condition in which excessive phytoplankton growth is followed by decay and oxygen depletion. For

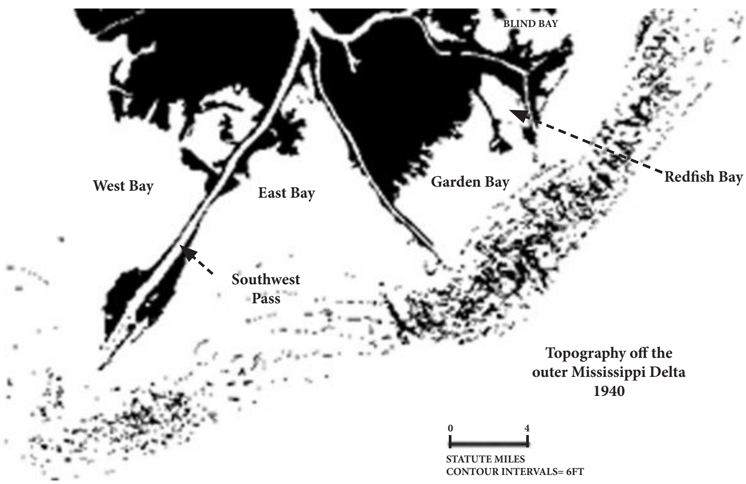

Fig. 7. Delta of the Mississippi River. The prevailing circulation is that of a saltwedge estuary. After Shepard, F.P., 1955. Delta–front Valleys Bordering the Mississippi Distributaries. In Volume 66 of the Bulletin of the Geological Society of America.

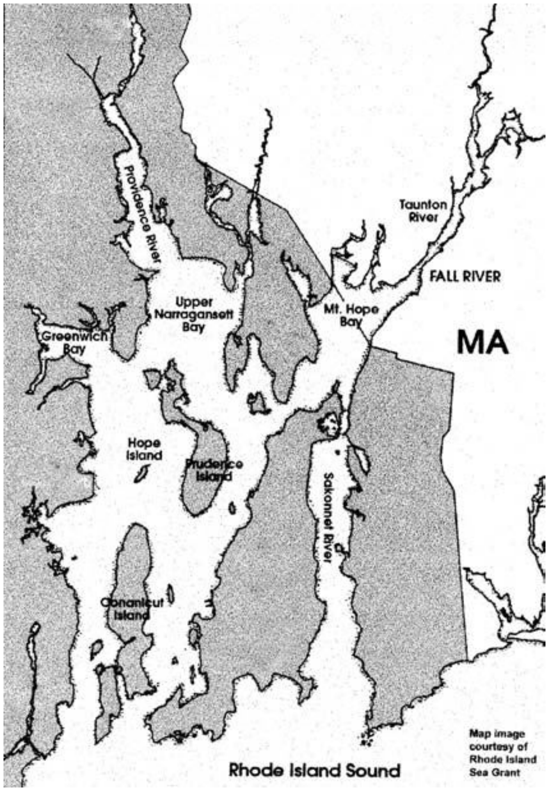

Fig. 8. Narragansett Bay—an example of a partially-mixed estuary. Shaded area is Rhode Island; unshaded is Massachusetts. Source: R.I. Sea Grant Program.

most estuaries, any large amount of pollutants draining into the system is undesirable. However, in many estuarine environments. An adequate nutrient supply and the associated primary productivity often favors the growth of oysters, clams, mussels, and other shellfish and supports local crab and finfish populations. Shellfish and finfish may also be cultivated in impoundments along the bay-mouth settings. Furthermore, such enriched estuarine environments are often very important for those species, such as salmonids and alewives, that migrate from offshore to spawn in the freshwater of the upper tributaries (Fig. 9). As the young subsequently migrate out to sea, they are nourished as they pass through enriched estuarine areas.

Actually, the reproductive history of the common eel that runs into the freshwater streams is played out in reverse. In the Atlantic, eels migrate from upstream to a site approximately in mid-ocean where they spawn at great depths. Though the eels from North American tributaries and those from European waters spawn close together, their larvae return to the continents where their parents had been nurtured.

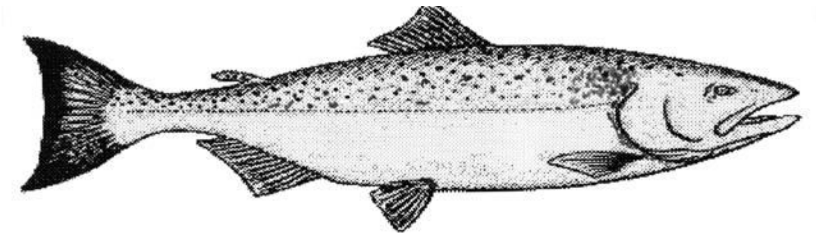

Fig. 9. Coho Salmon. Several species of salmon inhabit estuarine environments as they migrate upriver to spawn. Their offspring occupy the same productive areas on their way out to sea.

Unfortunately, estuarine settings may be burdened by deposits of silt brought from up-river. Where this occurs, you often see dredging going on to maintain navigation channels.

In addition to the ecological attributes of the various estuarine settings, the surroundings serve development in a number of ways. Many of the major shipping ports of the world are located on such river-mouth areas (Fig. 10). Various manufacturing ventures, taking advantage of the transportation possibilities and, in some cases, needing the ready supply of water, have been established in such locations. As to fisheries, estuaries may not only be highly productive, as just mentioned, but may also serve as convenient harbors for offshore fishing craft. Similarly, many recreational craft are moored or docked in the marinas along the estuarine shorelines (Fig. 10). Finally, you will often find that locations near the sea are heavily populated simply because these are attractive places in which to live.

In essence, a busy estuary is a multiple-use area involving industrial development, shipping activities, shellfish, and finfish harvesting including mariculture in some cases, fishing port, and seafood processing activities, extensive housing for the people living in such locales, and all the service enterprises that the above activities require (Fig. 11).

Fig. 10. Yachts at a marina in Yaquina Bay.

With all their attributes, the related opportunities, and the accompanying problems such as pollution, many estuarine systems and neighboring coastal environments have become the focus of a great deal of attention. A number of oceanographers, not only realizing the importance of these environments but also finding that by their very nature they are scientifically challenging, have increasingly focused on estuarine and related coastal studies. Along with this, many who are interested in economics, public affairs, and related management issues are focusing on the estuarine and the nearby coastal environments in what has become known as the interdisciplinary field of *Coastal Zone Management*.

Fig. 11. A tugboat tows an old freighter down the bay and under the Chesapeake Bay Bridge. Source: NOAA.

Appendix I.
Comments on Some Suggested Texts

An Introduction to the World's Oceans by Keith A. Sverdrup, Alyn C. Duxbury and Alison B. Duxbury. Current edition.* McGraw Hill, New York.

Excellent, up-to-date, and very readable with superb illustrations and numerous interesting side bars. Suggested readings and internet sources are included. Written primarily for use as an introductory college course.

Oceanography, A View of the Earth by M. Grant Gross and Elizabeth Gross. Current Edition.* Prentice Hall, Upper Saddle River, New Jersey.

Quite comparable in content and style to Sverdrup et al. cited above.

Introduction to Oceanography by Harold V. Thurman and Elizabeth A. Burton. Current edition.* Prentice Hall, Upper Saddle River, New Jersey.

Also quite comparable to Sverdrup et al. cited above.

The Open University in England publishes a series of books primarily intended for instruction by correspondence. These include the following publications:

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* Judging from the number of successive editions published, it is obvious that these books are well suited for and have been widely adopted as college texts. A number of other authors have written very good introductory texts. You should be able to find many of these by browsing in a library specializing in oceanography or in the appropriate section of a general library.

Ocean Circulation
Waves, Tides and Shallow-Water Processes
Seawater: Its Composition, Properties, and Behavior.
These are written by an Oceanography Course Team of the Open University and published by Butterworth-Heinemann, Oxford. Current editions available.

Biological Oceanography by Carol M. Lalli and Timothy R. Parsons. Current edition. Pergamon Press, Oxford.
This is published in the style of the above books and, accordingly, is listed as an Open University oceanography book. All books in the Open University oceanography series are well written with illustrations that are very helpful. Study suggestions and related learning exercises are included.

The Open Sea: Its Natural History by Sir Alister Hardy, 1965. Houghton Mifflin, Boston.
This is a classic, every bit as helpful as the title suggests, and widely referred to by biological oceanographers and marine biologists. Though out-of-print it may be found in many libraries and in used book stores.

Descriptive Physical Oceanography: An Introduction by George L. Pickard and William J. Emery. 5th edition, 1990. Pergamon Press, Oxford.
By effectively describing the highlights of physical oceanography, the authors render an important service for readers who might otherwise be frustrated by the mathematics in most presentations of this subject.

Oceanography and Seamanship by William G. Van Dorn, 1974. Dodd, Mead & CO., New York.
Contains material of special interest to those concerned with ship and boat operations.

Sea and Air, The Naval Environment by Jerome Williams, John J. Higginson and John D. Rohrbough, 1968. U.S. Naval Academy, Annapolis, Maryland.
Some of the content is of special interest to those in the Navy, Coast Guard and Merchant Marine.

Exploring the Oceans by Henry. S. Parker, 1985. Prentice Hall, Englewood Cliffs, New Jersey.

Some would include this with the impressive series of books written primarily as introductory texts but Parker's approach differs in that he often places the reader in the role of a participant on board a research vessel. In fact, in the final chapter the reader dreams of taking a comprehensive oceanographic expedition around the world.

Appendix II. Some Convenient Conversions

Distance

1 kilometer (km) = 1,000 meters = 0.62 statute miles
= 0.54 nautical miles

1 meter (m) = 100 centimeters = 3.28 feet = 39.37 inches

1 statute mile (mile) = 5,280 feet = 0.87 nautical miles
= 1609 meters

1 nautical mile (naut mile) = 1 minute of latitude = 6,076 feet = 1.15 miles
= 1852 meters

1 fathom (fm) = 6 feet = 1.83 meters

1 inch (in) = 2.56 centimeters

1 centimeter (cm) = 10 millimeters = 0.39 inches

1 foot (ft) = 30.49 cm

Velocity
1 knot = 1 nautical mile /hour = 1.15 miles/hour = 1.85 km/hour

1 mile/hour (mph) = 0.87 knots = 1.61 kilometer/hour

Temperature
°Centigrade (°C) = (°F -32) 5/9
°Fahrenheit (°F) = (9/5°C) +32

Constants
Mean depth of the oceans is approximately= 4,000 meters or 13,000 ft

Appendix III. Trolling While Underway

It can be rewarding to trail a line hoping to catch a fish while underway. If you are not going too fast and there is not too much flotsam repeatedly fouling your rig, this may be a good way to get something fresh and tasty for your next meal. You can seldom be sure just what you might catch and, when a fish does bite, you will probably have to haul it in without slowing down, particularly if you are under sail.

You can try to do this with a heavy rod and reel, either in hand or somehow fastened in place. However, it often seems more practical to simply let out a very strong line, probably nylon because of its good stretching qualities and almost 1/8 inch in diameter since you can't anticipate how much strain may be involved. You will want a length of shock cord near the end of the line, followed by a good-size swivel, and a feather jig. Without some idea as to what might bite, selecting the jig is guess work. Probably you should err on the large size. Having a gaff and a net to boat whatever you chance to catch would obviously be useful.

If you are sailing downwind under steady, moderate winds and waves, the line will need very little attention if after tying it down, you carry it forward and attach it to a shroud with a clip that will release if something strikes.

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Nelson Marshall

While engaged in professional oceanographic research and teaching, Marshall, like the postman who goes for a hike on Sundays, spent much of his free time cruising in his 30-foot auxiliary sloop. Underway he realized that, with the equipment readily available on vessels, whether large or small, interested observers could learn a great deal about their surroundings. This prompted him, in his retirement, to write *Oceanography: An Observer's Guide.*

Professor Marshall earned a Bachelor of Science degree at Rollins College, a Master of Science at Ohio State University and a PhD at the University of Florida. The list of oceanographic institutions in which he served includes the Virginia Fisheries Laboratory (now the Virginia Institute of Marine Sciences of the College of William and Mary), the Woods Hole Oceanographic Institution, the Rosensteil School of Marine and Atmospheric Sciences of the University of Miami, the Oceanographic Institute of Florida State University, and, finally, the Graduate School of Oceanography of the University of Rhode Island from which he retired as Professor Emeritus of Oceanography and Marine Affairs after 24 years devoted to both teaching and research.

In retirement, Marshall continued his oceanographic interests through associations with nearby academic centers, first with the Horn Point Laboratory of the University of Maryland Center for Environmental Science and then with the College of Oceanographic and Atmospheric Sciences of Oregon State University. He published three other books for the purpose of fostering public interest in matters relating to the sea. These are:

Understanding the Eastern Caribbean and the Antilles
The Scallop Estuary
In the Wake of a Great Yankee Oceanographer: Recollections from the Years Following the Foundations Laid Down by Henry Bryant Bigelow

It was Professor Marshall's hope that *Oceanography: An Observer's Guide* would enrich the experience of all who travel on the high seas.

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